Midwest Research Institute

Safety Evaluation of the Safety Edge Treatment

Final Report

For
University of North Carolina
Highway Safety Research Center

Federal Highway Administration
Office of Safety Research and Development

MRI Project No. 110495.1.001

July 2010

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For
University of North Carolina
Highway Safety Research Center
Chapel Hill, North Carolina 27599

Federal Highway Administration
Office of Safety Research and Development
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16. Abstract

Pavement-shoulder drop-offs may form along the pavement edge of highways between periods of maintenance. Such drop-offs may hinder smooth reentry to the roadway by drivers who run off the roadway and may lead to driver over-correction, loss of control, or overturning on the roadway or roadside. The safety edge is a treatment that is implemented in conjunction with pavement resurfacing and is intended to help minimize drop-off-related crashes. This paper examines the safety effects, costs, and benefits of this low-cost treatment for two-lane and multilane rural highways. The safety research was conducted as an observational before-after evaluation of treated sites using the Empirical Bayes method. The economic appraisal consisted of a benefit-cost analysis. The safety evaluation found that the safety edge treatment appears to have a small, positive crash reduction effect. The best effectiveness measure for the safety edge treatment was a 5.7 percent reduction in total crashes on rural two-lane highways. However, this result was not statistically significant. The economic analysis found that the treatment is very inexpensive and that it is highly cost-effective for application for a broad range of conditions on two-lane highways. Non consistent results were found for rural multilane highways because the available data sample was very small.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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Section 1.
Background and Research Objectives

This section of the report describes the background and objectives for this research and describes the organization of the remainder of this report.

1.1 Purpose of the Safety Edge Treatment

Two-lane rural highways often have unpaved shoulders immediately adjacent to the traveled way. Other two-lane highways, and many multilane rural highways, have narrow paved shoulders with widths of 0.3 to 1.2 m (1 to 4 ft.) If roadway maintenance forces do not keep material against the pavement edge, a pavement-shoulder drop-off may form. The drop-off height can vary from less than 25 mm (1 inch) to 152 mm (6 inches) or more, even though maintenance performance standards usually require maintenance when the drop-off exceeds 38 to 51 mm (1.5 to 2 inches) (*1*).

When a vehicle leaves the traveled way and encounters a pavement-shoulder drop-off, it may be difficult for the driver to return safely to the traveled way. As the driver attempts to steer back onto the roadway, the side of the tire may scrub along the drop-off, resisting the driver's attempts to steer and make a smooth reentry to the roadway. This resistance often leads to driver over-correction with a greater steering angle than desired to remount the drop-off. When the tire does remount the pavement drop-off, the increased tire angle may "slingshot" the vehicle across the road, resulting in a collision with other traffic or loss of control and overturning on the roadway or roadside.

The safety edge is a treatment that is intended to minimize drop-off-related crashes. With this treatment, the pavement edge is formed at a sloped angle of 30 degrees to lessen the resistance of the tire to remounting the drop-off (see Figure 1). The lessened resistance is intended to allow a more controlled reentry onto the traveled way.

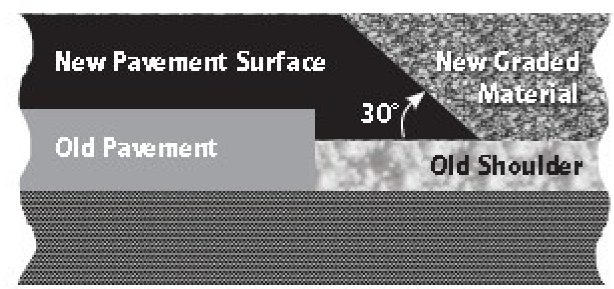

Figure 1. Safety Edge Detail

Research conducted by Texas Transportation Institute (*2*) in the 1980's found that drivers rated a 45° wedge as a much safer pavement edge to remount than either a vertical or rounded edge normally found with PCC or asphalt pavements. While the TTI research was criticized as not being representative of naïve drivers (drivers in the study were instructed to go off the pavement edge) actual field evaluation of the safety edge has not been completed prior to this research.

Selected highway agencies have begun to use the safety edge treatment as part of pavement resurfacing projects. However, there has been no formal evaluation of the effectiveness of this treatment in reducing drop-off-related crashes on rural highways. Such an evaluation is needed to determine whether this treatment should receive more widespread use.

1.2 Research Objectives and Scope

Eight state highway agencies have joined with FHWA in a pooled-fund study to implement and evaluate the safety edge treatment in conjunction with pavement resurfacing projects. Four of these agencies provided study sites for this evaluation. They are the Colorado Department of Transportation, the Georgia Department of Transportation, the Indiana Department of Transportation, and the New York State Department of Transportation. The evaluation of the safety edge treatment extends over a three-year period. This final report presents the evaluation results for the three years after implementation of the treatment. Year 1 and Year 2 interim reports were prepared for the first and second year after implementation of the safety edge treatment. This final report discusses the entire three-year study.

The primary objective of the evaluation is to quantify the safety effectiveness of the safety edge treatment. An evaluation was performed to determine whether provision of the safety edge treatment as part of a pavement resurfacing project reduces crashes in comparison to pavement resurfacing without the safety edge treatment. The evaluation results are presented in terms of the percentage reduction in specific target crash types that can be expected from the provision of the safety edge treatment. Other objectives of the study are to document the effectiveness of the safety edge treatment in reducing the presence of pavement edge drop-offs and to perform an economic analysis of the safety edge treatment. The economic analysis uses the safety effectiveness evaluation results and project cost data to define the types of roadways and traffic volume levels for which provision of the safety edge treatment would be cost effective.

The project scope includes two-lane rural roads with no paved shoulder and with a paved shoulder no wider than 1.2 m (4 ft). Multilane roads with paved shoulders no wider than 1.2 m (4 ft) are also studied.

1.3 Summary of Evaluation Plan

The evaluation plan for the safety edge treatment is based on three types of sites:

- sites that were resurfaced and treated with the safety edge (referred to as *treatment* sites);
- sites that were resurfaced, but not treated with the safety edge (referred to as *comparison* sites);
- sites that were similar to the treatment and comparison sites, but were not resurfaced (referred to a *reference* sites).

This final report is based on data for the characteristics and performance of the treatment, comparison, and reference sites during the period before the treatment and comparison sites were resurfaced and for three years after resurfacing. Data collected and analyzed in this report includes field measurements of drop-offs present on the treated sites before, and during the three years after resurfacing; crash records for two to five years before the site was resurfaced and three years after resurfacing; traffic volumes and road characteristics for each site, and the date and cost of resurfacing of the treatment and comparison sites.

This report presents the results of a comparison of the presence of pavement edge drop-offs between the treatment and comparison sites for the period before resurfacing and during the three years after resurfacing.

The report also presents the safety evaluation results using traffic volume and crash data for the period before resurfacing of the treatment and comparison sites and three years after resurfacing. Two statistical approaches were used to analyze these data: (1) a before-after comparison using Empirical Bayes (EB) method and (2) a cross-sectional comparison of the safety performance of sites that were resurfaced with and without the safety edge treatment, based on the after period only.

For use in the before-after EB analysis to estimate the safety performance of the safety edge treatment, safety performance functions (SPFs) were developed from the reference site data using negative binomial regression analysis.

The frequencies of specific target crash types were used as the dependent variables for the safety evaluation. All of the target crashes for the safety evaluation exclude at-intersection and intersection-related crashes, since the safety edge treatment is targeted primarily at nonintersection crashes.

Safety measures used as dependent variables for this report include the frequencies of total nonintersection crashes, run-off-road crashes, and drop-off-related crashes. Run-off-road crashes included those crashes in which one or more involved vehicles left the road. Drop-off-related crashes were a subset of run-off-road crashes for which the crash data included specific evidence that a pavement edge drop-off may have been involved, such as the inclusion of “low shoulder” or “shoulder defect” as a contributing factor. Separate analyses were conducted for each target crash type for fatal-and-injury crashes, property-damage-only crashes, and all crash severity levels combined.

Cost data for the resurfacing projects at the treatment and comparison sites are presented in the report, and findings are presented concerning the cost-effectiveness of the safety edge treatment.

1.4 Organization of This Report

The remainder of this report is organized as follows. Section 2 documents the project database including a summary of the length of the sites studied, the crash data analyzed, traffic volumes and characteristics of the sites, and field measurements of the pavement edge drop-offs. Section 3 presents the analysis results for the field measurements of pavement edge drop-offs. Section 4 presents the safety effectiveness evaluation. Section 5 presents project cost comparisons for sites resurfaced with and without the safety edge. Section 6 presents the benefit-cost economic analysis, Section 7 presents conclusions drawn from the analysis results, and Section 8 presents recommendations based on results of the three-year evaluation.

Section 2. Project Database

Evaluation of the safety edge treatment requires data on roadway geometrics, traffic volumes, crashes, construction costs, and implementation projects for sites where the safety edge treatment was implemented and for other similar sites. This section of the report describes the selection of sites and assembly of the project database.

2.1 Participating States and Site Selection

Three states agreed to implement the safety edge treatment and to participate in the study: Georgia, Indiana, and New York. Colorado also agreed to participate in the study but no sites were resurfaced with the safety edge treatment in time for inclusion in the analysis. Sites for the study were selected with the assistance of the participating state highway agencies. However, the site selection approach varied for three types of study sites: sites that were resurfaced and treated with the safety edge (referred to as *treatment* sites); sites that were resurfaced, but not treated with the safety edge (referred to as *comparison* sites); and sites that were similar to the treatment and comparison sites but were not resurfaced (referred to as *reference* sites).

Treatment sites were selected by the three participating states from among the sites considered for their normal resurfacing program for the year 2005. In Indiana and New York, the sites that received the safety edge treatment were selected by the state as representative resurfacing projects for which the safety edge treatment would be appropriate. In Georgia, the Georgia Department of Transportation made a policy decision to include the safety edge treatment in all resurfacing projects let in April 2005 or thereafter. The treatment sites for this evaluation were drawn from among the projects let after that date.

Most of the sites selected by the state highway agencies were used in this evaluation. A few sites that were distinctly different from the remainder of the study sites were dropped from the evaluation. Based on a preliminary review of the available treated projects in Georgia, Indiana, and New York, a decision was reached to focus the analysis on three types of roadway segments:

- Rural multilane roadways with paved shoulders with widths of 1.2 m (4 ft) or less
- Rural two-lane roadways with paved shoulders with widths of 1.2 m (4 ft) or less
- Rural two-lane roadways with no paved shoulders (i.e., unpaved shoulders only)

Comparison sites were selected from among projects that were resurfaced in 2005 that did not receive the safety edge treatment. In Georgia, the comparison sites were resurfacing projects that were let to contract prior to April 2005 and, thus, before the date on which the Georgia Department of Transportation implemented the safety edge treatment in all resurfacing projects. The comparison sites were selected to include the same roadway types as the treatment sites. The comparison sites were located in the same highway districts as the treatment sites, so they were located in the same geographical area within the state.

Reference sites in each participating state included sites that had not been resurfaced during the study period before resurfacing of the treatment and comparison sites and were not expected to be resurfaced during the entire three-year study period. The reference sites included the same roadway types as the treatment and comparison sites. The total length of reference sites selected in each state was at least the same as the length of treated sites in the state and often larger. Reference sites were chosen from the same highway districts as the treatment sites, so they are located in the same geographical area of the state. Input from district engineers was sought to ensure that the reference sites were similar to the treatment sites in that area. No reference sites were selected in New York because the reference sites are needed only for the before-after EB evaluation and it appeared unlikely that an EB evaluation could be conducted for the limited set of treatment sites available in New York. The New York data could be included in other planned evaluations without the need for reference sites.

Each resurfacing project was divided into smaller roadway segments, as needed, based on a review of site characteristics and traffic volumes to assure that each site was relatively homogenous with respect to lane width, shoulder type and width, and traffic volume. The project database includes 415 sites: 261 in Georgia, 148 in Indiana, and 6 in New York. The individual sites ranged in length from 0.2 to 41.5 km (0.1 to 25.8 mi). The total length of all segments considered in the study was 1,102 km (685 mi) in Georgia, 827 km (514 mi) in Indiana, and 40 km (25 mi) in New York. Table 1 summarizes the number of sites by state, roadway type, shoulder type, and site type.

Table 1. Summary of Number and Total Length of Sites

State	Roadway type	Shoulder type	Site type[a]	Number of sites	Length(mi)
GA	Multilane	Paved	T	10	18.9
			C	7	12.9
			R	15	23.5
	Two-lane	Paved	T	25	53.0
			C	19	26.9
			R	53	201.9
		Unpaved	T	22	45.2
			C	31	92.8
			R	79	210.1
		Combined		261	685.3
IN	Two-lane	Paved	T	14	25.5
			C	7	21.3
			R	29	101.3
		Unpaved	T	16	58.0
			C	18	71.2
			R	64	237.0
		Combined		148	514.1
NY	Two-lane	Paved	T	3	10.0
			C	3	15.2
		Combined		6	25.2

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
R = Reference sites not resurfaced

Table 1 shows that the project database includes 90 sites, with a total length of 340 km (211 mi), at which the safety edge treatment was implemented. This includes 57 treatment sites in Georgia, 30 treatment sites in Indiana, and 3 treatment sites in New York. The project database also includes 85 comparison sites with a total length of 386 km (240 mi) and 240 reference sites with a total length of 1,245 km (774 mi).

2.2 Data Collection

A substantial amount of data were collected and assembled into a database for consideration in the analysis phase of this study. The data collected include data for the period before resurfacing of the treatment and comparison sites and for three years after resurfacing. Information concerning data availability, data collection procedures, and contents is presented below for the following data types:

- Project locations and roadway characteristics
- Crashes
- Traffic volumes
- Field measurements of pavement edge drop-offs

2.2.1 Project Locations and Roadway Characteristics

For each treatment, comparison, and reference site, the project database includes the following data elements: location on the agency's highway system, project construction dates, and basic roadway characteristics. The basic roadway characteristics obtained include: road type, lane width, and shoulder type and width. These data were obtained from state highway databases or published reports. All state data were verified and supplemented from field visits to the sites.

Analysis units for the study (i.e., study sites) were created by subdividing resurfacing projects into sections that were generally homogeneous with respect to roadway geometrics. The roadway characteristics used to define the site boundaries were monitored for changes other than resurfacing.

2.2.2 Crashes

The crash database for the study includes all nonintersection crashes that occurred within the limits of each site during the study period. Crash data, provided by the participating agencies from their electronic crash record databases, contained sufficient summary information to identify the target crash types most likely to be affected by provision of the safety edge.

Where possible, it is desirable to limit the evaluation to specific target crash types that are most likely affected by the implementation of safety edge treatment. If the crash data for both the before and after periods include crash types that could not conceivably be affected by the safety edge treatment, then this "noise" could introduce unnecessary variability into the crash counts that may mask the safety effect of the treatment. For example, the installation of the safety edge treatment is likely to have a greater effect on run-off-road crashes than on rear-end crashes. By limiting the analysis to include only run-off-road crashes, the likelihood of finding statistically significant effects may be improved. However, at the same time, the more restrictive the crash type definition used, the smaller the crash counts available for analysis; smaller crash counts make it more difficult to find statistically significant effects. Because of this tradeoff between the relevance of the target crash type to the treatment being evaluated and the number of crashes available for analysis, a range of target crash type definitions, from more inclusive and less relevant to less inclusive and more relevant was considered.

The selection of the target crash types to be evaluated was guided by two recent studies of crashes related to pavement/shoulder edge drop-offs by Council (*3*) and Hallmark et al. (*1*). These studies identified five scenarios (crash sequences) under which over-steering may occur resulting in a crash related to a pavement edge drop-off. This report assumes that only these types of crashes and no other would be affected by provision of the safety edge.

The five types of crashes used to identify potential drop-off-related crashes are:

1. Head-on collision with an oncoming vehicle
2. Sideswipe collision with an oncoming vehicle
3. Run-off-road crash on the opposite side of the road
4. Overturning within the traveled way or on the opposite side of the road
5. Same-direction sideswipe collisions on multilane roads

Of course, head-on crashes may involve a vehicle that crossed the centerline without first running off the road; such head-on crashes have not been classified as drop-off-related nor treated as target crashes.

The target crash types described above represent ***potential*** drop-off-related crashes, defined as precisely as possible without obtaining and reviewing individual hard-copy police crash forms. Past research by Council (*3*) that included a detailed analysis of hard copy reports indicated that a larger percentage of potential crashes were judged as probable or possible drop-off crashes when the officer had noted a shoulder defect. Therefore, if the agency's crash form had an item for "low shoulder" or "shoulder defect," then this item was used to identify potential drop-off crashes.

The above methodology represents a narrow interpretation of drop-off-related crashes. Therefore, it was also recommended that crashes which show evidence of a vehicle leaving the road or run-off-the-road crashes be included, such as:

- Run-off-road right, cross centerline/median, hit vehicle traveling in the opposite direction (head-on or sideswipe)
- Run-off-road right, sideswipe with vehicle in same direction (multilane roads)
- Run-off-road right, rollover (could be in road or roadside)
- Run-off-road right, then run-off-road left
- Single vehicle run-off-road right

Selection of the crash types was based on descriptors in the crash database furnished by the participating states. The data fields used included sequence of events, location of first harmful event, type of collision, driver, and roadway contributing circumstances. The specific fields used to identify drop-off-related crashes in this study for each participating state are described in Appendix A.

Crash severity levels considered in the evaluation are:

- Fatal, injury, and property-damage-only (PDO) crashes (i.e., all crash severity levels combined)
- Fatal-and-injury crashes
- PDO crashes

The highest priority in assessment of the safety edge treatment is the evaluation of its effect on fatal-and-injury crashes because these categories include the most severe crashes among the target crash types of interest. Crashes of all severity levels (i.e., also including PDO crashes) were also considered because the larger crash sample size may make it easier to detect statistically significant improvement effects. Although it is more desirable to consider only PDO crashes that are sufficiently severe that at least one of the involved vehicles is towed from the crash scene, since PDO tow-away crashes are more consistently reported than other PDO crashes, this exclusion was not applied in this study as only one of the participating states (Indiana) identified tow-away crashes in their data.

Tables 2 and 3 summarize the crash data including the breakdown of total, run-off-the-road, and drop-off-related crashes for each state, roadway type, shoulder type, and site type for total and fatal-and-injury crashes, respectively.

Indiana was only able to provide reference-point (i.e., milepost) information, and latitude and longitude information, for some of the crashes. Additionally, some of the reference-point information provided with the crashes indicated that the crashes occurred on side roads at intersections. Approximately 40 percent of the crashes had wrong or missing reference point or coordinate information, but contained a verbal description of the crash. Extensive efforts to better locate these crashes were undertaken during the execution of the work plan.

Table 2. Summary of Total Nonintersection Crash Data for Study Sites

State	Roadway type	Shoulder type	Site type[a]	Number of sites	Dates for study periods		Site length (mi)	Number of crashes during before and after study periods combined[b]		
					Before resurfacing	After resurfacing		Total crashes	Run-off-road crashes	Drop-off-related crashes
GA	Multilane	Paved	T	10	1999 to 2004	2006 to 2008	18.9	563	162	99
			C	7	1999 to 2004	2006 to 2008	12.9	368	120	81
			R	15	1999 to 2004	2006 to 2008	23.5	927	199	118
	Two-lane	Paved	T	25	1999 to 2004	2006 to 2008	53.0	844	306	186
			C	19	1999 to 2004	2006 to 2008	26.9	475	223	157
			R	53	1999 to 2004	2006 to 2008	201.9	2,489	924	573
		Unpaved	T	22	1999 to 2004	2006 to 2008	45.2	820	335	216
			C	31	1999 to 2004	2006 to 2008	92.8	874	427	289
			R	79	1999 to 2004	2006 to 2008	210.1	2,105	995	631
			Combined	261	1999 to 2004	2006 to 2008	685.3	9,465	3,691	2,350
IN	Two-lane	Paved	T	14	2003 to 2004	2006 to 2008	25.5	250	58	12
			C	7	2003 to 2004	2006 to 2008	21.3	234	55	25
			R	29	2003 to 2004	2006 to 2008	101.3	646	176	59
		Unpaved	T	16	2003 to 2004	2006 to 2008	58.0	169	59	16
			C	18	2003 to 2004	2006 to 2008	71.2	287	145	73
			R	64	2003 to 2004	2006 to 2008	237.0	810	260	96
			Combined	148	2003 to 2004	2006 to 2008	514.1	2,396	753	281
NY	Two-lane	Paved	T	3	1999 to 2004	2006 to 2008	10.0	130	66	3
			C	3	1999 to 2004	2006 to 2008	15.2	218	79	4
			Combined	6	1999 to 2004	2006 to 2008	25.2	348	145	7
Combined				415			1,224.6	12,209	4,589	2,638

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
R = Reference sites not resurfaced

[b] Does not include at-intersection or intersection-related crashes.

Table 3. Summary of Fatal-and-Injury Nonintersection Crash Data for Study Sites

State	Roadway type	Shoulder type	Site type[a]	Number of sites	Dates for study periods: Before resurfacing	Dates for study periods: After resurfacing	Site length (mi)	Number of fatal-and-injury crashes during before and after study periods combined[b]: Total crashes	Run-off-road crashes	Drop-off-related crashes
GA	Multilane	Paved	T	10	1999 to 2004	2006 to 2008	18.9	154	64	47
			C	7	1999 to 2004	2006 to 2008	12.9	121	49	37
			R	15	1999 to 2004	2006 to 2008	23.5	366	108	71
	Two-lane	Paved	T	25	1999 to 2004	2006 to 2008	53.0	313	137	99
			C	19	1999 to 2004	2006 to 2008	26.9	229	125	96
			R	53	1999 to 2004	2006 to 2008	201.9	856	437	315
		Unpaved	T	22	1999 to 2004	2006 to 2008	45.2	279	162	120
			C	31	1999 to 2004	2006 to 2008	92.8	374	225	166
			R	79	1999 to 2004	2006 to 2008	210.1	892	512	366
			Combined	261	1999 to 2004	2006 to 2008	685.3	3,584	1,819	1,317
IN	Two-lane	Paved	T	14	2003 to 2004	2006 to 2008	25.5	37	14	3
			C	7	2003 to 2004	2006 to 2008	21.3	57	20	7
			R	29	2003 to 2004	2006 to 2008	101.3	129	73	29
		Unpaved	T	16	2003 to 2004	2006 to 2008	58.0	31	18	5
			C	18	2003 to 2004	2006 to 2008	71.2	83	58	32
			R	64	2003 to 2004	2006 to 2008	237.0	141	91	35
			Combined	148	2003 to 2004	2006 to 2008	514.1	478	274	111
NY	Two-lane	Paved	T	3	1999 to 2004	2006 to 2008	10.0	59	42	3
			C	3	1999 to 2004	2006 to 2008	15.2	75	42	3
			Combined	6	1999 to 2004	2006 to 2008	25.2	134	84	6
Combined				415			1,224.6	4,196	2,177	1,434

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
R = Reference sites not resurfaced

[b] Does not include at-intersection or intersection-related crashes.

2.2.3 Traffic Volumes

Annual average daily traffic volume (AADT) data for all study locations were obtained through agency databases or published sources from each of the participating agencies, so no field traffic counts were required as part of the database development. When possible, separate AADT values for each year of the study period were obtained. When AADT values were not available for all years of the study period, values were interpolated or extrapolated for the missing years.

Table 4 summarizes the traffic volume data assembled for the project database. Ideally, the AADT ranges should be as similar as possible for the various site types within each state/road type/shoulder type combination. In particular, it was desirable for reference sites to cover the entire range of values of the treatment and comparison sites, as SPF performance outside the range of the reference sites is not optimum. It was also desirable that the comparison and reference sites have nearly identical ranges. The AADT ranges were found to be similar for most cases except for multilane highways sites with paved shoulders in Georgia. For these sites, the AADT ranges are higher for treatment sites than for comparison or reference sites. To a lesser extent, the same is true for two-lane highway sites with paved shoulders in Indiana.

2.2.4 Lane Width

Lane widths ranged from 2.7 to 4.0 m (9 to 13 ft) across all sites and states, with the majority of lanes being 3.6 m (12 ft) wide. The distribution of lane width is summarized in Table 5 by state and site type. The variability in lane width is most evident for the unpaved shoulder type, so it was decided to include this variable in modeling efforts for these sites.

2.2.5 Field Drop-Off Measurements

Field visits were made to each treatment and comparison site to collect pavement edge drop-off measurements, as well as additional geometric design variables. Field measurements of pavement edge drop-offs were made before resurfacing and during each of the three years after resurfacing. However, some of the project sites were resurfaced before field visits could be made which prevented this supplemental data collection before resurfacing at some sites. Drop-off height was measured 4 inches from the pavement edge for all types of sites (treatment and comparison). The types of data collected and the methodology for collecting these data are documented in Appendix B.

Table 4. Summary of Traffic Volume Data for Study Sites

State	Roadway type	Shoulder type	Site type[a]	Number of sites	Site length (mi)	AADT (veh/day) Minimum	AADT (veh/day) Mean before resurfacing	AADT (veh/day) Mean after resurfacing	AADT (veh/day) Maximum
GA	Multilane	Paved	T	10	18.9	7,639	15,417	14,966	23,825
			C	7	12.9	4,467	9,988	11,148	22,160
			R	15	23.5	6,087	10,060	10,373	22,302
			Combined	32	55.3	4,467	11,874	12,124	23,825
	Two-lane	Paved	T	25	53.0	410	4,046	3,983	13,237
			C	19	26.9	1,453	4,929	6,104	11,247
			R	53	201.9	397	4,118	4,122	18,697
			Combined	97	281.9	397	4,182	4,285	18,697
		Unpaved	T	22	45.2	1,285	3,418	3,601	9,650
			C	31	92.8	413	3,134	2,976	15,000
			R	79	210.1	310	2,996	3,001	9,660
			Combined	132	348.1	310	3,087	3,073	15,000
IN	Two-lane	Paved	T	14	25.5	2,198	6,584	6,561	14,662
			C	7	21.3	3,406	5,067	5,047	7,457
			R	29	101.3	1,170	4,046	4,056	8,958
			Combined	50	148.0	1,170	4,629	4,629	14,662
		Unpaved	T	16	58.0	376	1,444	1,436	3,158
			C	18	71.2	996	1,858	1,845	6,423
			R	64	237.0	478	2,554	2,548	13,615
			Combined	98	366.1	376	2,243	2,235	13,615
NY	Two-lane	Paved	T	3	10.0	1,058	3,601	3,776	5,797
			C	3	15.2	1,110	3,687	3,693	7,047
			Combined	6	25.2	1,058	3,653	3,726	7,047
Combined				415	1,224.6	310	3,682	3,712	23,825

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
R = Reference sites not resurfaced

Table 5. Summary of Lane Widths for Study Sites

State	Road type	Shoulder type	Site type	Number of sites	Site length (mi)	Lane width(ft)		
						Minimum	Mean	Maximum
GA	Multilane	Paved	T	10	18.9	12	12.3	13
			C	7	12.9	12	12.7	13
			R	15	23.5	12	12.3	13
			Combined	32	55.3	12	12.4	13
	Two-lane	Paved	T	25	53.0	11	12.0	13
			C	19	26.9	12	12.6	13
			R	53	201.9	11	12.3	13
			Combined	97	281.9	11	12.3	13
		Unpaved	T	22	45.2	11	11.9	13
			C	31	92.8	10	12.0	13
			R	79	210.1	10	12.2	13
			Combined	132	348.1	10	12.1	13
IN	Two-lane	Paved	T	14	25.5	12	12.0	13
			C	7	21.3	12	12.2	13
			R	29	101.3	9	11.5	13
			Combined	50	148.0	9	11.8	13
		Unpaved	T	16	58.0	10	11.4	13
			C	18	71.2	9	10.2	11
			R	64	237.0	9	11.3	13
			Combined	98	366.1	9	11.1	13
NY	Two-lane	Paved	T	3	10.0	10	10.6	11
			C	3	15.2	9	11.0	12
			Combined	6	25.2	9	10.8	12

Section 3. Preliminary Analysis Results for Field Measurements of Pavement Edge Drop-Offs

This section presents preliminary analysis results for field measurements of pavement edge drop-offs. Field measurements of drop-off heights were made to evaluate the comparability of existing pavement edge drop-offs for the treatment and comparison sites in the period before resurfacing and to verify that the safety edge treatment does not encourage the development of pavement edge drop-offs in the period after resurfacing. Both of these analyses are discussed in this section.

Field data for pavement edge drop-off heights were collected for each participating agency for both treatment and comparison sites in the period before resurfacing and during each year after resurfacing. The field data collection methodology is presented in Appendix B of this report. A few sites were resurfaced before field visits could be made. Consequently, these sites were excluded from the analysis of before-period drop-off height data presented below.

3.1 Comparison of Pavement Edge Drop-Off Measurements for Treatment and Comparison Sites in the Period Before Resurfacing

A formal assessment of the comparability of the treatment and comparison sites with respect to the presence of pavement edge drop-offs in the period before resurfacing was undertaken. The measure used for this comparison was the proportion of drop-off heights that exceed 51 mm (2 inches). This criterion was used based on research indicating that pavement edge drop-off heights that exceed 51 mm (2 inches) may affect safety (*1*). It should be noted that this previous research was conducted on sites without the safety edge treatment.

It would be desirable if the proportion of sites with pavement edge drop-off heights that exceed 51 mm (2 inches) were similar for the treatment and comparison sites in the period before resurfacing. An analysis to make this comparison was conducted by performing a logistic regression analysis using the LOGISTIC procedure in SAS software (*4*). This procedure uses the Fisher scoring method to estimate the statistical significance of differences in proportions between the treatment and comparison sites.

Ideal results for this analysis would have been obtained if the difference between the proportions of drop-off heights over 51 mm (2 inches) for the treatment and comparison sites were not statistically significant at some predetermined significance level. A statistically significant result would be indicated by an odds ratio point estimate that was significantly greater than or less than 1.0 (i.e., the confidence interval for the odds ratio does not contain 1.0). Conversely, for a difference that is not statistically significant, the odds ratio for the difference would contain 1.0. If odds ratio could not be determined by maximum likelihood due to small sample size or poor variation of responses (i.e., identical responses for each site type or non-overlapping responses between site types), then an exact test was performed and a median unbiased estimate of the odds ratio is provided.

The results of this analysis for each state, roadway type, shoulder type, and treatment type combination, including the frequency and proportion of measurements above 51 mm (2 inches), the odds ratio point estimate, the odds ratio confidence interval, and statistical significance of the odds ratio point estimate are given in Table 6. Odds ratio values above 1.0 in this table indicate that comparison sites have a greater probability of experiencing drop-offs above 51 mm (2 inches) than treatment sites.

The results in Table 6 indicate that in the period before resurfacing, there were relatively equal proportions of extreme drop-off heights between treatment and comparison sites for Georgia sites on multilane highways with paved shoulders and two-lane highways with unpaved shoulders. This finding indicates that these two types of sites are relatively well matched in terms of shoulder conditions in the period before resurfacing. By contrast, for Georgia sites on two-lane highways with paved shoulders, evidence suggests that there is a statistically significant chance that comparison sites have greater proportions at drop-offs above 51 mm (2 inches).

For Indiana sites on two-lane highways with paved shoulders, there are a greater proportion of extreme drop-off heights for the comparison sites than for the treatment sites in the period before resurfacing, although it is not statistically significant. The opposite is the case for Indiana sites on two-lane highways with unpaved shoulders and for New York sites on two-lane highways with paved shoulders. In these cases, the treatment and comparison sites are not perfectly matched in terms of shoulder conditions in the period before resurfacing. For Indiana, this difference is statistically significant. Some differences of this sort may have been inevitable because resurfacing projects that received the safety edge treatment were not selected based on consideration of the existing shoulder condition. This is a potential confounding factor that should be considered in interpreting the research results.

3.2 Comparison of Pavement Edge Drop-Off Measurements for Treatment and Comparison Sites Between the Periods Before and After Resurfacing

The field measurement data for pavement edge drop-offs were initially reviewed by state, roadway type, shoulder type, and treatment type. For each study period, Table 7 presents summary descriptive statistics for these measures. Histograms for a sample of the distributions in Figure 2 show the impact of resurfacing for both treatment and comparison sites.

Table 6. Comparison of the Proportions of Drop-Off Heights That Exceed 2 inches Between the Treatment and Comparison Sites for the Period Before Resurfacing

State	Roadway type	Shoulder type	Site type	Drop-off heights that exceed 2 inches		Odds ratio point estimate	Lower confidence limit	Upper confidence limit	Statistically significant at 0.05 level?
				Number	Proportion				
GA	Multilane	Paved	T	2	0.07				
			C	5	0.06	0.909	0.184	6.596	N
	Two-lane	Paved	T	10	0.03				
			C	25	0.14	4.591	2.211	10.259	Y
		Unpaved	T	23	0.09				
			C	29	0.13	1.557	0.876	2.799	N
IN	Two-lane	Paved	T	6	0.04				
			C	10	0.10	2.519	0.902	7.642	N
		Unpaved	T	150	0.39				
			C	53	0.22	0.423	0.291	0.608	Y
NY	Two-lane	Paved	T	36	0.38				
			C	0	0.00	0.028	0.000	1.620	N[b]

[a] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge
[b] Indicates that median unbiased estimate was used.

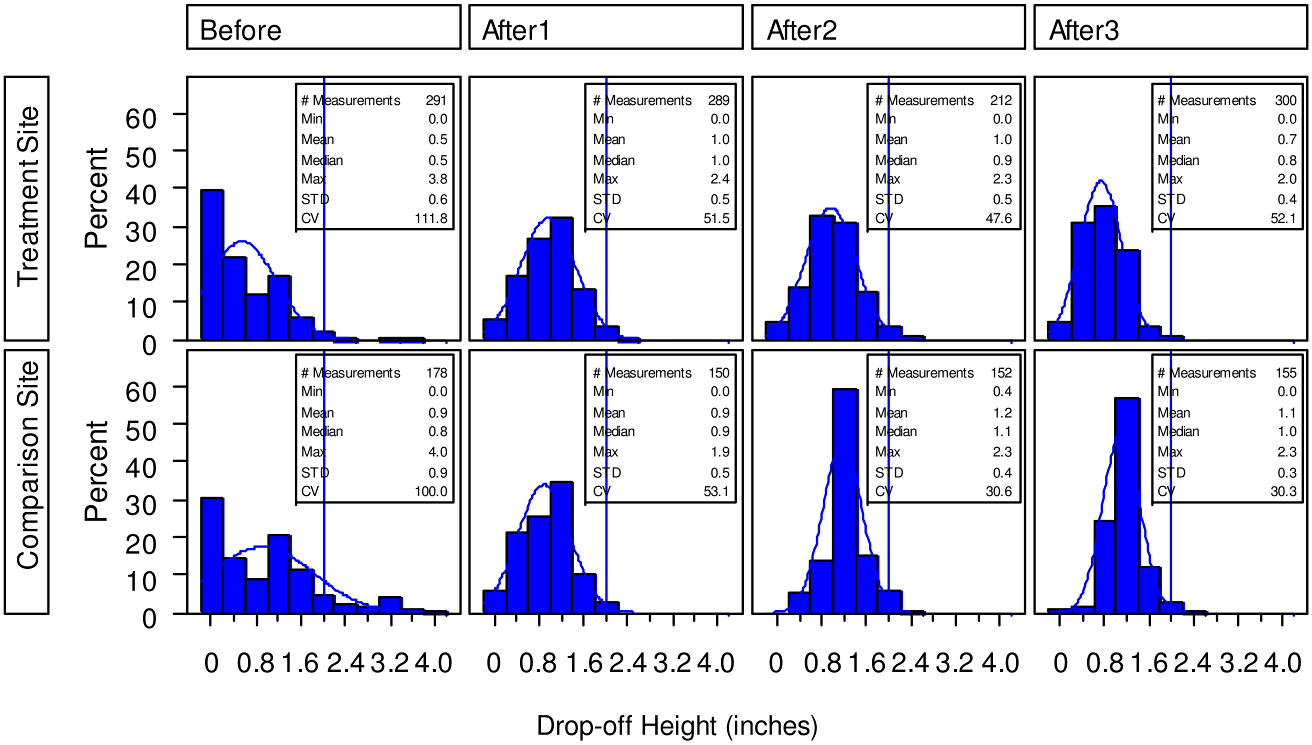

Figure 2. Drop-off Height Measurement Distributions for Two-Lane Highways With Paved Shoulders in Georgia

Table 7. Summary of Pavement Edge Drop-Off Height Measurements

State	Road type	Shoulder type	Site type	Before resurfacing							After resurfacing (Year 1)						
				Number of measure-ments	Drop-off height (inches)						Number of measure-ments	Drop-off height (inches)					
					Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %		Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %
GA	Multilane	Paved	T	30	0	0.783	0.750	2.000	0.618	79	59	0.375	1.047	0.875	2.875	0.504	48
			C	82	0	0.811	0.750	3.000	0.710	88	86	0.250	1.038	1.000	2.375	0.467	45
	Two-lane	Paved	T	291	0	0.546	0.500	3.750	0.611	112	289	0.000	0.960	1.000	2.375	0.495	52
			C	178	0	0.912	0.750	4.000	0.912	100	150	0.000	0.887	0.875	1.875	0.471	53
		Unpaved	T	270	0	0.881	0.750	3.750	0.695	79	273	0.000	0.941	0.875	2.500	0.495	53
			C	229	0	1.076	1.000	4.750	0.804	75	466	0.000	0.945	0.875	2.875	0.556	59
IN	Two-lane	Paved	T	136	0	0.630	0.500	3.500	0.598	95	158	0.000	0.703	0.625	1.875	0.356	51
			C	96	0	0.960	0.750	3.250	0.708	74	137	0.250	1.340	1.125	4.250	0.707	53
		Unpaved	T	380	0	1.758	1.625	5.125	0.778	44	367	0.250	1.653	1.500	4.500	0.737	45
			C	245	0	1.353	1.250	6.875	0.930	69	279	0.125	1.168	1.000	5.250	0.673	58
NY	Two-lane	Paved	T	94	0	1.681	1.500	5.125	1.270	76	77	0.000	1.110	0.875	4.000	0.886	80
			C	42	0	0.777	0.750	1.750	0.487	63	83	0.000	1.065	1.000	2.750	0.480	45

State	Road type	Shoulder type	Site type	After resurfacing (Year 2)							After resurfacing (Year 3)						
				Number of measure-ments	Drop-off height (inches)						Number of measure-ments	Drop-off height (inches)					
					Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %		Minimum	Mean	Median	Maximum	Standard deviation	Coefficient of variation %
GA	Multilane	Paved	T	65	0.500	1.175	1.000	3.000	0.448	38	65	0.500	1.175	1.000	3.000	0.448	38
			C	86	0.250	0.906	0.813	2.500	0.455	50	86	0.250	0.907	0.875	2.500	0.442	49
	Two-lane	Paved	T	212	0.000	0.956	0.875	2.250	0.455	48	254	0.000	1.087	1.000	3.375	0.432	40
			C	152	0.375	1.166	1.125	2.250	0.356	31	164	0.250	1.104	1.125	2.250	0.372	34
		Unpaved	T	238	0.125	1.179	1.000	3.563	0.571	48	259	0.250	1.107	1.000	3.563	0.566	51
			C	426	0.000	1.163	1.125	3.250	0.548	47	448	0.000	1.119	1.063	3.250	0.526	47
IN	Two-lane	Paved	T	187	0.000	0.788	0.750	2.250	0.379	48	189	0.125	0.780	0.750	2.250	0.398	51
			C	102	0.250	1.456	1.250	4.375	0.857	59	147	0.000	1.344	1.250	3.875	0.609	45
		Unpaved	T	370	0.250	1.916	1.750	6.875	0.993	52	373	0.250	1.584	1.375	4.500	0.774	49
			C	280	0.000	1.353	1.250	5.500	0.764	56	290	0.125	1.236	1.125	4.500	0.676	55
NY	Two-lane	Paved	T	78	0.375	1.786	1.344	5.125	1.191	67	78	0.375	1.786	1.344	5.125	1.191	67
			C	81	0.625	1.446	1.375	3.250	0.497	34	81	0.625	1.446	1.375	3.250	0.497	34

The mean drop-off height did not vary between the before and after periods. For almost all roadway type/shoulder type/treatment type combinations, the coefficient of variation (i.e., relative standard deviation) of drop-off height decreased substantially between the before resurfacing and each of the first two years after resurfacing, but increased again following the second year after resurfacing.

To formally assess whether the safety edge treatment has any effect on pavement/shoulder edge drop-offs, a trend analysis evaluating the change in drop-offs from before to after resurfacing was conducted. Specifically, the proportion of drop-off height measurements that exceed 51 mm (2 inches) was evaluated to determine if there were differences between the before and after study periods. This analysis was carried out using the same logistic regression approach presented in Section 3.1. However, in this case, the proportions of drop-off heights that exceed 51 mm (2 inches) were compared between the periods before and after resurfacing for each type of site rather than between treatment and comparison sites.

The ideal trend for this analysis would be indicated by a substantial decrease in drop-off height for the period one year after resurfacing, possibly followed by a slow increasing trend in the later years back to the drop-off height that existed before resurfacing. To evaluate this trend, all pairwise comparisons between years were evaluated for statistical significance. Four of the comparisons: Before vs. After Year 1, After Year 1 vs. After Year 2, After Year 2 vs. After Year 3, and Before vs. After Year 3 have been summarized.

For Before vs. After Year 1, an odds ratio point estimate less than 1.0 indicates that After Year 1 has more drop-off heights that exceed 51 mm (2 inches) than the period before resurfacing. A confidence interval for the odds ratio that does not contain the value 1.0 indicates statistical significance. Since the odds ratios were less than 1.0 in 3 of the 12 cases shown in Table 8, the sites in After Year 1 generally had fewer drop-off heights above 51 mm (2 inches), than the sites in the period before resurfacing. Also, the three cases when After Year 1 had more drop-off exceeding 51 mm (2 inches) than the period before resurfacing were not significant. Thus, it appears that resurfacing tends to reduce the proportion of extreme drop-off heights.

The odds ratio for the treatment sites was less than 1.0 for one out of six cases, indicating that resurfacing with the safety edge treatment is effective in reducing the proportion of extreme drop-off heights. Resurfacing without the safety edge treatment was effective in reducing the proportion of extreme drop-off heights in four of six cases. Additionally, none of the observed odds ratios less than 1.0 and almost all of the observed odds ratios greater than 1.0 were statistically significant.

Table 8. Comparison of the Proportions of Drop-Off Heights That Exceed 2 inches for the Treatment and Comparison Sites Between the Periods Before and After Resurfacing

State	Roadway type	Shoulder type	Site Type	Test	Proportion Period 1	Proportion Period 2	Odds ratio point estimate	Lower 95% confidence limit	Upper 95% confidence limit	Statistically significant at the 0.05 level?
GA	Multilane	Paved	C	Period Before vs AfterY1	0.06	0.06	1.05	0.28	3.92	N
GA	Multilane	Paved	C	Period Before vs AfterY2	0.06	0.03	1.80	0.43	8.99	N
GA	Multilane	Paved	C	Period Before vs AfterY3	0.06	0.08	0.73	0.21	2.39	N
GA	Multilane	Paved	C	Period AfterY1 vs AfterY2	0.06	0.03	0.59	0.12	2.46	N
GA	Multilane	Paved	C	Period AfterY1 vs AfterY3	0.06	0.08	1.44	0.44	5.03	N
GA	Multilane	Paved	C	Period AfterY2 vs AfterY3	0.03	0.08	2.45	0.66	11.68	N
GA	Multilane	Paved	T	Period Before vs AfterY1	0.07	0.07	0.98	0.13	5.35	N
GA	Multilane	Paved	T	Period Before vs AfterY2	0.07	0.08	0.86	0.12	4.25	N
GA	Multilane	Paved	T	Period Before vs AfterY3	0.07	0.09	0.70	0.10	3.27	N
GA	Multilane	Paved	T	Period AfterY1 vs AfterY2	0.07	0.08	1.15	0.29	4.83	N
GA	Multilane	Paved	T	Period AfterY1 vs AfterY3	0.07	0.09	1.40	0.38	5.72	N
GA	Multilane	Paved	T	Period AfterY2 vs AfterY3	0.08	0.09	1.22	0.35	4.44	N
GA	Two-lane	Paved	C	Period Before vs AfterY1	0.14	0	infinity	12.13	infinity	Y
GA	Two-lane	Paved	C	Period Before vs AfterY2	0.14	0.05	3.38	1.49	8.70	Y
GA	Two-lane	Paved	C	Period Before vs AfterY3	0.14	0.03	6.17	2.33	21.32	Y
GA	Two-lane	Paved	C	Period AfterY1 vs AfterY2	0	0.05	infinity	3.24	infinity	Y
GA	Two-lane	Paved	C	Period AfterY1 vs AfterY3	0	0.03	infinity	1.60	infinity	Y
GA	Two-lane	Paved	C	Period AfterY2 vs AfterY3	0.05	0.03	0.55	0.14	1.86	N
GA	Two-lane	Paved	T	Period Before vs AfterY1	0.03	0.03	1.11	0.44	2.83	N
GA	Two-lane	Paved	T	Period Before vs AfterY2	0.03	0.02	1.85	0.61	6.82	N
GA	Two-lane	Paved	T	Period Before vs AfterY3	0.03	0	10.64	2.02	195.83	Y
GA	Two-lane	Paved	T	Period AfterY1 vs AfterY2	0.03	0.02	0.60	0.16	1.86	N
GA	Two-lane	Paved	T	Period AfterY1 vs AfterY3	0.03	0	0.10	0.01	0.56	Y
GA	Two-lane	Paved	T	Period AfterY2 vs AfterY3	0.02	0	0.17	0.01	1.19	N
GA	Two-lane	Unpaved	C	Period Before vs AfterY1	0.13	0.06	2.36	1.36	4.10	Y
GA	Two-lane	Unpaved	C	Period Before vs AfterY2	0.13	0.1	1.29	0.78	2.12	N
GA	Two-lane	Unpaved	C	Period Before vs AfterY3	0.13	0.08	1.68	0.99	2.84	N
GA	Two-lane	Unpaved	C	Period AfterY1 vs AfterY2	0.06	0.1	1.83	1.11	3.04	Y
GA	Two-lane	Unpaved	C	Period AfterY1 vs AfterY3	0.06	0.08	1.40	0.83	2.38	N
GA	Two-lane	Unpaved	C	Period AfterY2 vs AfterY3	0.1	0.08	0.77	0.48	1.23	N
GA	Two-lane	Unpaved	T	Period Before vs AfterY1	0.09	0.03	2.73	1.28	6.34	Y
GA	Two-lane	Unpaved	T	Period Before vs AfterY2	0.09	0.13	0.62	0.35	1.10	N
GA	Two-lane	Unpaved	T	Period Before vs AfterY3	0.09	0.09	0.99	0.53	1.85	N
GA	Two-lane	Unpaved	T	Period AfterY1 vs AfterY2	0.03	0.13	4.39	2.13	9.99	Y
GA	Two-lane	Unpaved	T	Period AfterY1 vs AfterY3	0.03	0.09	2.76	1.28	6.46	Y
GA	Two-lane	Unpaved	T	Period AfterY2 vs AfterY3	0.13	0.09	0.63	0.35	1.12	N
IN	Two-lane	Paved	C	Period Before vs AfterY1	0.10	0.17	0.58	0.25	1.24	N
IN	Two-lane	Paved	C	Period Before vs AfterY2	0.10	0.27	0.31	0.13	0.66	Y
IN	Two-lane	Paved	C	Period Before vs AfterY3	0.10	0.1	0.70	0.30	1.52	N
IN	Two-lane	Paved	C	Period AfterY1 vs AfterY2	0.17	0.27	1.88	1.01	3.53	Y
IN	Two-lane	Paved	C	Period AfterY1 vs AfterY3	0.17	0.14	0.83	0.43	1.57	N
IN	Two-lane	Paved	C	Period AfterY2 vs AfterY3	0.27	0.14	0.44	0.23	0.83	Y

Table 8. Comparison of the Proportions of Drop-Off Heights That Exceed 2 inches for the Treatment and Comparison Sites Between the Periods Before and After Resurfacing (Continued)

State	Roadway type	Shoulder type	Site Type	Test	Proportion Period 1	Proportion Period 2	Odds ratio point estimate	Lower 95% confidence limit	Upper 95% confidence limit	Statistically significant at the 0.05 level?
			T	Period Before vs AfterY1	0.04	0	infinity	3.18	infinity	Y
IN	Two-lane	Paved	T	Period Before vs AfterY2	0.04	0.01	8.58	1.44	163.10	Y
			T	Period Before vs AfterY3	0.04	0.02	2.86	0.74	13.75	N
			T	Period AfterY1 vs AfterY2	0.00	0.01	infinity	0.15	infinity	N
			T	Period AfterY1 vs AfterY3	0.00	0.02	infinity	0.94	infinity	N
			T	Period AfterY2 vs AfterY3	0.01	0.02	3.00	0.38	60.92	N
		Unpaved	C	Period Before vs AfterY1	0.22	0.11	2.21	1.37	3.61	Y
			C	Period Before vs AfterY2	0.22	0.16	1.48	0.95	2.31	N
			C	Period Before vs AfterY3	0.22	0.14	1.68	1.07	2.64	Y
			C	Period AfterY1 vs AfterY2	0.11	0.16	1.49	0.91	2.46	N
			C	Period AfterY1 vs AfterY3	0.11	0.14	1.32	0.80	2.18	N
			C	Period AfterY2 vs AfterY3	0.16	0.14	0.88	0.56	1.40	N
			T	Period Before vs AfterY1	0.39	0.28	1.65	1.22	2.24	Y
			T	Period Before vs AfterY2	0.39	0.42	0.88	0.66	1.18	N
			T	Period Before vs AfterY3	0.39	0.30	1.52	1.12	2.06	Y
			T	Period AfterY1 vs AfterY2	0.28	0.42	1.86	1.37	2.54	Y
			T	Period AfterY1 vs AfterY3	0.28	0.30	1.09	0.79	1.49	N
			T	Period AfterY2 vs AfterY3	0.42	0.30	0.58	0.43	0.79	Y
NY	Two-lane	Paved	C	Period Before vs AfterY1	0	0.02	-infinity	-infinity	3.18	N
			C	Period Before vs AfterY2	0	0.12	-infinity	-infinity	0.37	Y
			C	Period Before vs AfterY3	0	0.18	-infinity	-infinity	0.23	Y
			C	Period AfterY1 vs AfterY2	0.02	0.12	5.70	1.44	37.92	Y
			C	Period AfterY1 vs AfterY3	0.02	0.18	9.07	2.44	58.83	Y
			C	Period AfterY2 vs AfterY3	0.12	0.18	1.59	0.67	3.89	N
			T	Period Before vs AfterY1	0.38	0.31	2.79	1.39	5.84	Y
			T	Period Before vs AfterY2	0.38	0.27	1.68	0.88	3.26	N
			T	Period Before vs AfterY3	0.38	0.27	1.72	0.91	3.30	N
			T	Period AfterY1 vs AfterY2	0.18	0.27	1.66	0.78	3.63	N
			T	Period AfterY1 vs AfterY3	0.18	0.27	1.62	0.77	3.52	N
			T	Period AfterY2 vs AfterY3	0.27	0.27	0.98	0.49	1.98	N

For After Year 1 vs. After Year 2, an odds ratio point estimate greater than 1.0 indicates that the second year after resurfacing has more drop-off heights that exceed 51 mm (2 inches) than the first year after resurfacing. Since there were more drop-off heights greater than 51 mm (2 inches) in After Year 2, as compared to After Year 1, in 10 of the 12 cases shown in Table 8, there appears to be deterioration of the shoulder condition in the second year after resurfacing. However, only about half of these observed differences in the proportion of drop-off heights greater than 51 mm (2 inches) were statistically significant at the 5-percent significance level.

For After Year 2 vs. After Year 3, an odds ratio point estimate greater than 1.0 indicates that the third year after resurfacing has more drop-off heights that exceed 51 mm (2 inches) than the second year after resurfacing. Since 7 of the 12 cases shown in Table 8 have an odds ratio point estimate of 1.0 (or nearly 1.0), which indicates no change in the proportion of drop-off heights exceeding 51 mm (2 in), there appears to be minimal deterioration of the shoulder condition in the third year after resurfacing.

The data for drop-off heights in the before period were compared to drop-off height data for After Year 3 to determine whether drop-off heights had increased to the levels that existed before resurfacing. For this comparison, an odds ratio point estimate less than 1.0 indicates that the After Year 3 has more drop-off heights that exceed 51 mm (2 inches) than the period before resurfacing. Since the odds ratios were greater than 1.0 in 7 of the 12 cases shown in Table 8, there does not seem to be much evidence to suggest the proportion of high drop-offs in After Year 3 differs from the before period.

A final comparison of drop-off height data was made between sites resurfaced with and without the safety edge treatment in the third year after resurfacing to determine if the safety edge treatment has any role in development of drop-offs. The results of this analysis are given in Table 9. Odds ratio values above 1.0 indicate that comparison sites have more drop-off heights above 51 mm (2 inches) than treatment sites.

The results in Table 9 indicate that there were no differences in extreme drop-offs between sites resurfaced with and without the safety edge in Georgia. In Indiana, sites resurfaced with the safety edge had fewer drop-offs for sites with paved shoulders. However, sites with unpaved shoulders showed the reverse trend. In New York, sites resurfaced without the safety edge had fewer proportions of extreme drop-off heights. Overall, these results taken together appear to be inconclusive.

The analysis of the field measurements of drop-off-heights suggests that resurfacing is effective in reducing the proportion of extreme drop-off heights and that resurfacing with the safety edge treatment does not increase the number of extreme drop-off heights and is similar to resurfacing without the safety edge treatment in reducing the proportion of extreme drop-off heights over time.

Table 9. Comparison of the Proportions of Drop-off Heights That Exceed 2 inches Between the Treatment and Comparison Sites for the Final Period After Resurfacing

State	Road type	Shoulder type	Site type	Drop-off heights that exceed 2 inches		Odds ratio point estimate	Lower 95% confidence limit	Upper 95% confidence limit	Statistically significant
				Number	Proportion				
GA	Multilane	Paved	C	2	0.02	0.286	0.040	1.374	N
			T	5	0.08				
	Two-lane	Paved	C	6	0.04	1.034	0.341	2.922	N
			T	9	0.04				
		Unpaved	C	38	0.08	0.796	0.476	1.349	N
			T	27	0.1				
IN	Two-lane	Paved	C	21	0.14	10.332	3.470	44.394	Y
			T	3	0.02				
		Unpaved	C	41	0.14	0.384	0.256	0.567	Y
			T	112	0.3				
NY	Two-lane	Paved	C	10	0.12	0.382	0.161	0.858	Y

Section 4. Analysis Results for Safety Evaluation

This section presents analysis results for the safety evaluation. The section presents the evaluation approach, the development of SPFs, and the safety evaluation results. The safety evaluation results include the findings of a before-period compatibility study, a before-after evaluation using the EB technique, a cross-sectional analysis, and an analysis of shifts in crash severity.

4.1 Evaluation Approach

Two statistical approaches were used to evaluate the safety effectiveness of the safety edge treatment: (1) a before-after comparison of the effect of pavement resurfacing with and without the safety edge treatment using the Empirical Bayes (EB) technique and (2) a cross-sectional comparison of the effect of pavement resurfacing with and without the safety edge treatment, based on after-period data only. These two evaluation approaches have been applied concurrently to provide alternative statistical approaches to the key issues being addressed. The following discussion describes these evaluations, including issues related to the specific nature of the safety edge treatment.

A key objective of the evaluation was to determine the safety effectiveness of the safety edge treatment while avoiding the potential confounding effects of regression to the mean and the safety effect of pavement resurfacing. Regression to the mean is a characteristic of repeated measures data in which observations move towards ("regress towards") the mean value over time. That is, if an observation in one year is unusually high, then the observation in the following year will nearly always be lower, returning to the mean (and vice versa). This phenomenon often leads to an overestimation or underestimation of safety for some sites. Thus, the effect of the treatment is likely to be partially confounded with the expected decrease or increase in crash experience from regression to the mean. Regression to the mean can only be accounted for with knowledge of the "normal" or expected value of before-period crash experience at the treated sites. The EB technique has the advantage of compensating for regression to the mean. The cross-sectional approach does not explicitly compensate for regression to the mean; this is a concern, but is lessened by the availability of three years of crash data for the period after resurfacing.

The second potential confounding effect is the safety effect of pavement resurfacing, since it is always used in conjunction with the safety edge treatment. Previous research has indicated that pavement resurfacing by itself may have an effect on safety, increasing crashes because of increased speeds. This effect was found in one study to be statistically significant, but was found to persist for only 12 to 30 months after resurfacing (*5*). However, a more recent, larger study in NCHRP Project 17-9(2) (*6*) found inconsistent results; increases in crash frequency with resurfacing were found in some states, but decreases in crash frequency with resurfacing were found in others. Therefore, the safety effects of the pavement resurfacing and installation of the safety edge treatment will be confounded, at least for some time, following resurfacing.

To address the safety effect of resurfacing as well as the confounding effect of resurfacing and the safety edge treatment, the study design was developed in the following ways. First, the study period after resurfacing was selected to be three years. This is sufficiently long as to extend beyond the duration of any short-term resurfacing effect. Annual interim evaluations to monitor time trends were conducted to evaluate this issue. Thus, the results for safety effectiveness of the safety edge treatment in the first and second-year interim reports may be confounded by the safety effect of pavement resurfacing, but it is expected that this confounding effect is lessened in the final results. Second, resurfaced sites both with and without the safety edge treatment are being considered. The ratio of safety between resurfaced sites with and without the safety edge treatment (i.e., the treatment and comparison sites) may represent an effect of the safety edge treatment as long as the sites can be assumed comparable in other respects.

The first evaluation approach is an observational before-after comparison using the EB technique, as formulated by Hauer (*7, 8*). The specific version of the EB technique used in this evaluation was that developed for the FHWA *SafetyAnalyst* software tools (*9*). The primary objective of the before-after evaluation is to compare the ***observed*** number of crashes after the treatment is implemented to the ***expected*** number of crashes in the after period, had the countermeasure not been implemented. This provides an estimate of the overall safety effectiveness of the countermeasure, expressed as a percent change in the crash frequency.

When performing before-after evaluations using the EB approach, it is typical for data to be collected at sites where the safety edge treatment was implemented (i.e., treatment sites) and at sites similar to the treatment sites with respect to area type (rural/urban), geometric design, and traffic volumes but where no countermeasure was installed. Data from this reference group of sites (i.e., where no countermeasure was installed) are used to create safety performance functions (SPFs) which are then used together with the observed crash counts at the treated sites in the before period to estimate the number of crashes that would have occurred at the treated sites in the after period if no improvement had been made. These SPFs are discussed in Section 4.2.

The comparability before resurfacing of the two types of resurfaced sites (i.e., treatment and comparison sites) is critical to interpreting the difference of the two estimated before-after effects as an effect of the safety edge treatment. For example, if one of the site types had a higher mean in the before period and both site types had the same mean in the after period, then the effectiveness of one treatment may be presumed greater than the other treatment. The comparability of sites before treatment was established through analysis of the before-period crash data. These analyses are discussed in Section 4.3.1.

The EB before-after evaluation produced an estimate of the effectiveness of (1) resurfacing with the safety edge (treatment sites), and (2) resurfacing only (comparison sites), separately for each target crash type in each state. From each pair of estimated percent changes in safety (treatment and comparison), the effect of the safety edge alone was estimated as the ratio between the two measures of effectiveness (i.e., comparison–treatment). For every combination of site characteristics under consideration, the mean and standard error of the percent change in target crash frequency and its statistical significance are presented in Section 4.3.2.

It is anticipated that the effectiveness measure being sought for the safety edge treatment will be relatively small since it is expected that the safety edge treatment will affect only certain crash types and will have the greatest impact on two-lane highways with no paved shoulders. Most such sites have relatively low traffic volume and are, therefore, not expected to have a high frequency of run-off-the-road and drop-off-related crashes.

The EB-based before-after comparison approach is theoretically the strongest approach to evaluations of this type. However, because of the confounding of the pavement resurfacing effect and the safety edge treatment effect, it cannot be assured that this approach correctly identifies the treatment effectiveness. Therefore, an alternative cross-sectional comparison approach was also conducted.

A cross-sectional evaluation of the after data at the treated sites was conducted to directly compare the crash data between the two types of treatment—resurfacing with the safety edge treatment and resurfacing without the safety edge treatment. Assuming that all roadway factors except resurfacing are held constant, then one could hypothesize that the differences in either after-period crash frequencies or crash severity distributions between treatment and comparison sites are due to the provision of the safety edge treatment. This comparison was made with a cross-sectional approach using data for the period after resurfacing, while accounting for the effects of AADT.

The cross-sectional comparison of crash data for the period after resurfacing was conducted using negative binomial regression models to compare the predicted crash frequencies of the sites for the period after resurfacing with the safety edge treatment to those resurfaced without the safety edge treatment. Site type (i.e., treatment vs. comparison which represents resurfacing with or without safety edge treatment) was the main factor of interest in the analysis. The effect of AADT was accounted for in this approach by quantifying the relationship between AADT and specific target crash types. When significant, the effect of lane width was also accounted for in the model. The safety edge treatment effect and its standard error were then calculated for each target crash type. The treatment effect was converted to a percent change in crash frequency for ease in interpreting the results. The results of the cross-sectional analysis are presented in Section 4.4.3.

In addition to evaluating mean crash frequencies, a comparison of the before-after data by crash severity level was performed to determine shifts in the crash severity distribution. These comparisons were accomplished by calculating a confidence interval for the average difference in proportions across all sites at a preselected significance level of 10 percent. However, a non-parametric statistical test, the Wilcoxin Signed Rank test

(*11*), was also applied as the differences in proportions may not follow a normal distribution. Results from this analysis are presented in Section 4.4.4.

4.2 Safety Performance Functions

This section documents the safety performance functions (SPFs) and the calibration factors developed for use in the before-after EB evaluation of the safety effectiveness of the safety edge treatment. SPFs are regression relationships between target crash frequencies and traffic volumes that can be used to predict the expected long-term crash frequency for a site. SPFs are used in the before-after EB evaluation to estimate what the safety performance of a treated site would be in the period after implementation of the treatment if the treatment had not been implemented.

Negative binomial regression models were developed using data from the reference group of untreated sites for use in three categories of target crashes: (All crash types combined, run-off-road crashes, and drop-off-related crashes.) There were two severity levels (total and fatal-and-injury crashes.) Thus, a total of six dependent variables were considered for three target crash types and two crash severity levels. Traffic volume and lane width were the only independent variables considered in SPFs. Separate models were developed for Georgia and Indiana for each of the three classifications of roadways identified early in this report:

- Rural multilane highways with paved shoulders with widths of 1.2 m (4 ft or less)
- Rural two-lane highways with paved shoulders with widths of 1.2 m (4 ft) or less
- Rural two-lane highways with no paved shoulders (i.e., unpaved shoulders only)

Regression models were not developed for New York due to the limited number of treated sites.

All regression models were developed to predict target crash frequencies per mile per year as a function of traffic volume and, in some cases, lane width in the following functional forms:

$$N = \exp(a + b \ln AADT) \quad \textbf{(1)}$$

$$N = \exp(a + b \ln AADT + c\,LW) \quad \textbf{(2)}$$

where:

N = predicted number of target crashes per mile per year
AADT = average daily traffic volume (veh/day) for the roadway segment

LW = lane width for the roadway segment (ft)
a,b,c = regression coefficients

The AADT in the regression models was statistically significant in all cases. The lane width term was included in the regression model only when it was statistically significant.

Two generalized linear modeling techniques were used to fit the data. The first method used a repeated measures correlation structure to model yearly crash counts for a site. In this method, the covariance structure, assuming compound symmetry, is estimated before final regression parameter estimates are determined by general estimating equations. Consequently, model convergence for this method is dependent on the covariance estimates as well as parameter estimates. When the model failed to converge for the covariance estimates, an alternative method was considered. In this method, yearly crash counts for a site were totaled and ADT values were averaged to create one summary record for a site. Regression parameter estimates were then directly estimated by maximum likelihood, without an additional covariance structure being estimated.

Both methods also produced an estimate of the overdispersion parameter, or the estimate for which the variance exceeds the mean. Overdispersion occurs in traffic data when a number of sites being modeled have zero accident counts, which creates variation in the data. When the estimate for dispersion was very small or even slightly negative, the model was re-fit assuming a constant value. Both methods were accomplished with the GENMOD procedure of SAS (*4*).

Statistically significant models were not found for all dependent variables for some road type/shoulder type combinations. In these three cases, the intercept coefficient of the total crashes or fatal and injury crashes model was adjusted by the proportion of the applicable dependent variable to produce the final model. The model coefficients with their standard errors are presented in Tables 10 and 11 for Georgia and Indiana, respectively. All AADT coefficients shown are significant at the 10-percent significance level or better. Lane width coefficients shown are significant at the 20-percent significance level or better. Total and fatal and injury crash SPFs for Georgia and Indiana are illustrated in Figures 3 and 7, respectively.

Table 10. SPFs for Georgia Sites

Roadway type	Shoulder type	Number of site-years	Intercept (standard error)	AADT coefficient (standard error)	Lane width coefficient (standard error)	Overdispersion parameter	R^2_{LR} (%)
Total crashes							
Multilane	Paved	192	-4.801 (1.608)	0.642 (0.172)		0.487	9.2
Two-lane	Paved	582	-8.921 (1.189)	1.108 (0.141)		0.724	36.4
Two-lane	Unpaved	792	-7.730 (0.783)	0.978 (0.095)		0.425	25.1
Fatal-and-injury crashes							
Multilane	Paved	192	-2.204 (1.752)	0.252 (0.184)		0.588	0.2
Two-lane	Paved	582	-7.818 (1.116)	0.853 (0.132)		0.401	21.3
Two-lane	Unpaved	792	-8.556 (0.796)	0.958 (0.098)		0.346	16.0
Property-damage-only crashes							
Multilane	Paved	192	-6.611 (1.747)	0.787 (0.189)		0.540	14.0
Two-lane	Paved	582	-11.414 (1.397)	1.349 (0.164)		0.982	34.6
Two-lane	Unpaved	792	-8.470 (0.981)	1.011 (0.119)		0.623	19.3
Total run-off-road crashes							
Multilane	Paved	192	-3.475 (2.145)	0.360 (0.228)		0.213	1.9
Two-lane	Paved	582	-2.625 (1.710)	0.783 (0.134)	-0.376 (0.109)	0.464	19.9
Two-lane	Unpaved	132	-4.405 (1.443)	0.757 (0.141)	-0.199 (0.106)	0.472	14.8
Fatal-and-injury run-off-road crashes							
Multilane	Paved	192	-3.425(1.752)	0.252 (0.184)		0.588	0.2
Two-lane	Paved	582	-1.848(1.618)	0.544 (0.128)	-0.339 (0.110)	0.374	8.1
Two-lane	Unpaved	132	-5.556(1.543)	0.743 (0.139)	-0.151 (0.115)	0.341	15.8
Property-damage-only run-off-road crashes							
Multilane	Paved	192	-7.742(3.004)	0.750 (0.320)		0.117	5.6
Two-lane	Paved	582	-5.029(2.236)	1.033 (0.154)	-0.406 (0.144)	0.598	19.2
Two-lane	Unpaved	132	-4.544(1.709)	0.752 (0.173)	-0.238 (0.126)	0.636	9.7
Total drop-off-related crashes							
Multilane	Paved	192	-3.583(2.126)	0.318 (0.226)		0.131	1.6
Two-lane	Paved	582	-4.586(2.069)	0.884 (0.169)	-0.327 (0.125)	0.585	16.3
Two-lane	Unpaved	132	-4.140(1.495)	0.770 (0.141)	-0.270 (0.114)	0.427	14.0
Fatal-and-injury drop-off-related crashes							
Multilane	Paved	192	-2.344(1.974)	0.113 (0.141)		0.294	0.1
Two-lane	Paved	582	-3.297(1.894)	0.604 (0.154)	-0.290 (0.121)	0.558	6.2
Two-lane	Unpaved	132	-4.869(1.654)	0.699 (0.148)	-0.209 (0.127)	0.357	11.9
Property-damage-only drop-off-related crashes							
Multilane	Paved	192	-6.690(3.194)	0.574 (0.340)		0.101	2.7
Two-lane	Paved	582	-8.291(3.272)	1.269 (0.217)	-0.359 (0.195)	0.754	16.3
Two-lane	Unpaved	792	-4.345(3.899)	0.872 (0.157)	-0.388 (0.290)	0.565	6.6

Table 11. SPFs for Indiana Sites

Road type	Shoulder Type	Number of site-years	Intercept (standard error)	AADT coefficient (standard error)	Lane width coefficient (standard error)	Overdispersion parameter	R^2_{LR} (%)
Total crashes							
Two-lane	Paved	100	-5.500(1.317)	0.737(0.154)		0.444	15.3
Two-lane	Unpaved	98	-3.865(1.118)	0.701(0.146)	-0.156(0.086)	0.654	15.5
Fatal-and-injury crashes							
Two-lane	Paved	100	-6.279(1.977)	0.642(0.233)		0.563	5.1
Two-lane	Unpaved	196	-2.707(1.305)	0.427(0.139)	-0.198(0.098)	0.211	7.2
Property-damage-only crashes							
Two-lane	Paved	100	-5.572(1.373)	0.718(0.161)		0.398	14.8
Two-lane	Unpaved	98	-4.348(1.153)	0.694(0.148)	-0.128(0.089)	0.661	15.9
Total run-off-road crashes							
Two-lane	Paved	100	-3.250(1.962)	0.303(0.231)		0.413	1.5
Two-lane	Unpaved	196	-1.700(1.221)	0.490(0.119)	-0.278(0.103)	0.438	10.9
Fatal-and-injury run-off-road crashes							
Two-lane	Paved	296	-3.127(1.034)	0.346(0.105)	-0.132(0.078)	0.154	2.5
Two-lane	Unpaved	196	-1.467(1.432)	0.331(0.129)	-0.284(0.102)	0.027	6.4
Property-damage-only run-off-road crashes							
Two-lane	Paved	100	-4.764(2.398)	0.426(0.286)		0.212	2.5
Two-lane	Unpaved	196	-2.752(1.260)	0.573(0.133)	-0.279(0.112)	0.540	8.6
Total drop-off-related crashes							
Two-lane	Paved	100	-4.477(3.598)	0.313(0.421)		0.738	0.6
Two-lane	Unpaved	98	-2.352(1.489)	0.356(0.192)	-0.232(0.111)	0.310	1.5
Fatal-and-injury drop-off-related crashes							
Two-lane	Paved	100	-7.772(1.977)	0.642(0.233)		0.563	5.1
Two-lane	Unpaved	98	-2.943(1.989)	0.227(0.258)	-0.167(0.147)	0.276	0.3
Property-damage-only drop-off-related crashes							
Two-lane	Paved	100	-7.464(5.554)	0.597(0.653)		0.623	1.4
Two-lane	Unpaved	98	-3.006(1.593)	0.419(0.209)	-0.266(0.122)	0.069	1.7

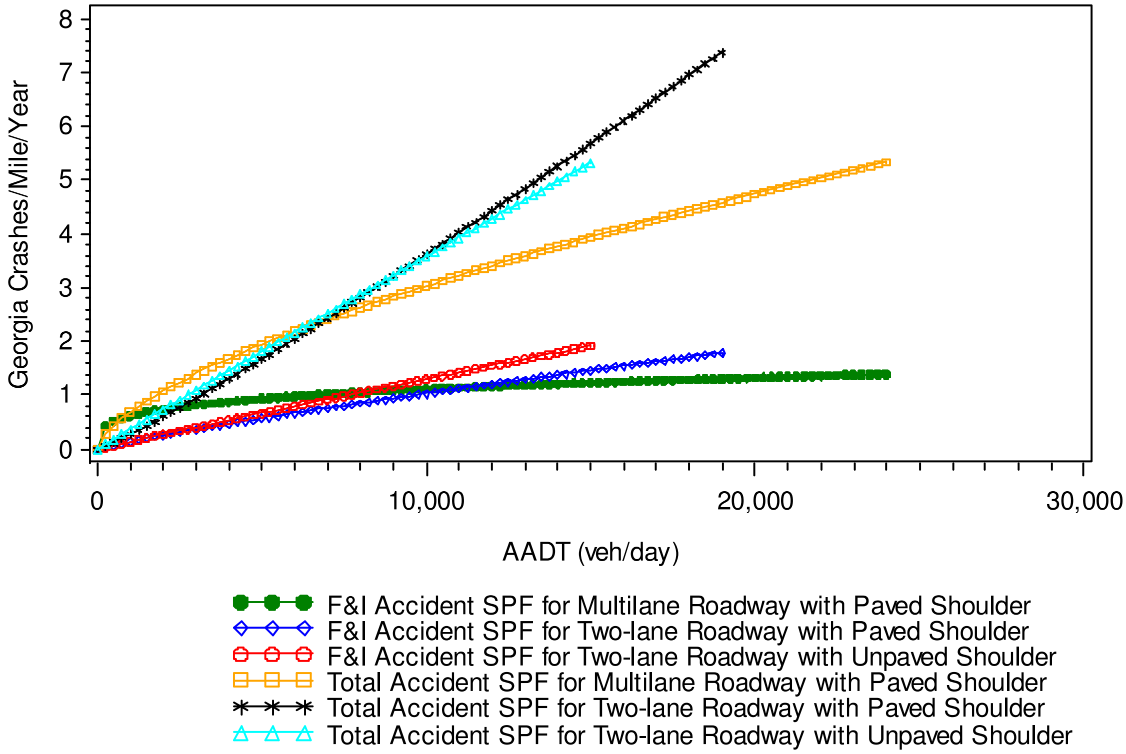

Figure 3. Comparison of Georgia SPFs by Crash Severity and Roadway and Shoulder Type

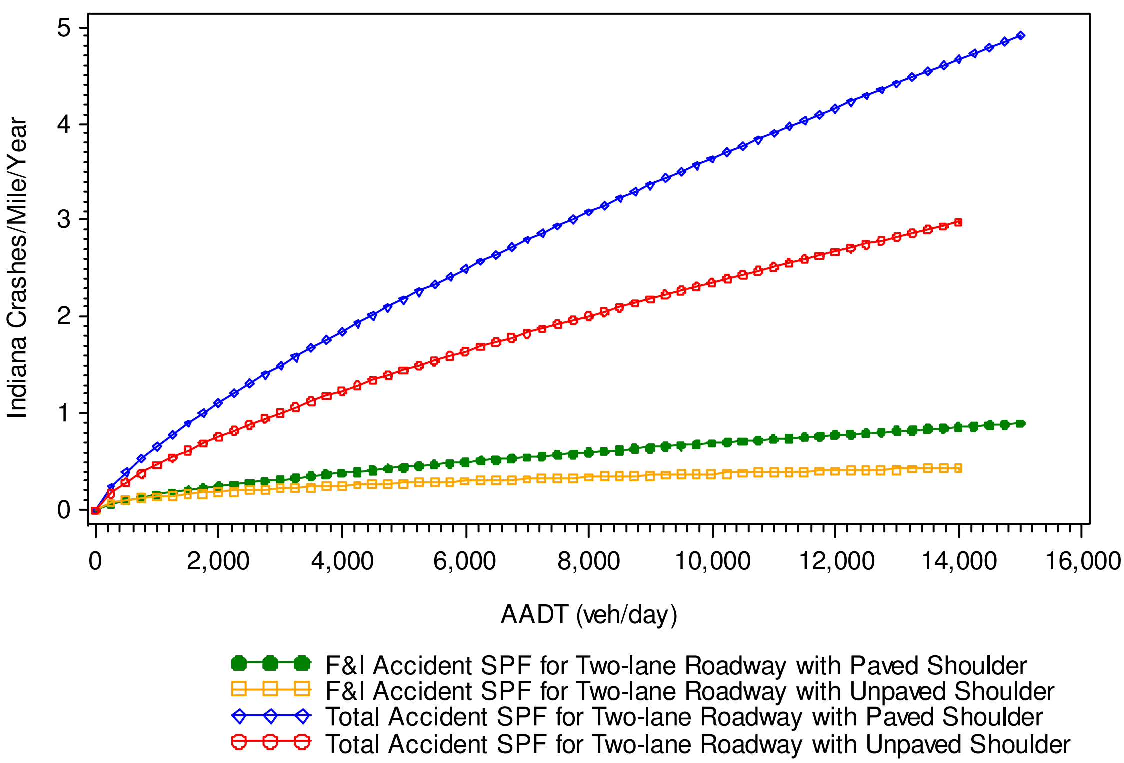

Figure 4. Comparison of Indiana SPFs by Crash Severity and Roadway and Shoulder Type

As noted earlier, the proportion of run-off-road and drop-off-related crashes, developed from reference sites, were sometimes needed to adjust total or fatal and injury SPFs for prediction of those crash types. Table 12 presents these proportions estimated from the reference site data.

Table 12. Run-Off-Road and Drop-off-Related Crash Frequencies as a Proportion of Total Crashes

State	Roadway type	Shoulder type	Crash Severity Level	Proportion of run-off-road crashes	Proportion of drop-off-related crashes
GA	Multilane	Paved	Total	0.215	0.127
			FI	0.295	0.194
			PDO	0.162	0.084
	Two-lane	Paved	Total	0.371	0.230
			FI	0.511	0.368
			PDO	0.298	0.158
		Unpaved	Total	0.473	0.300
			FI	0.574	0.410
			PDO	0.398	0.219
IN	Two-lane	Paved	Total	0.272	0.091
			FI	0.566	0.225
			PDO	0.199	0.058
		Unpaved	Total	0.321	0.119
			FI	0.645	0.248
			PDO	0.253	0.091

Additionally, yearly calibration factors were developed from the SPFs to provide a better yearly prediction in the methodology. These factors are needed because the SPFs are developed as an average of all years. The yearly calibration factor is determined as the ratio of the sum of observed crashes for all sites for a specific roadway type/shoulder type combination to the sum of the predicted crashes for the same sites using the AADT and crash count values for that year. These factors are presented in Tables 13 and 14 for Georgia and Indiana respectively.

Table 13. Georgia SPF Calibration Factors

Roadway type	Shoulder type	Crash severity level	Yearly calibration factors							
			2001	2002	2003	2004	2005	2006	2007	2008
Total crashes										
Multilane	Paved	Total	0.956	1.023	1.071	0.943	1.078	1.178	0.993	0.983
		FI	0.908	1.091	0.950	1.153	1.168	1.170	0.959	0.942
		PDO	0.998	1.005	1.155	0.849	1.049	1.203	1.031	1.021
Two-lane	Paved	Total	0.856	0.949	0.919	1.044	0.990	1.045	1.025	1.023
		FI	0.926	0.979	0.996	1.114	1.139	1.167	1.115	1.075
		PDO	0.823	0.933	0.873	0.998	0.905	0.977	0.969	0.990
	Unpaved	Total	0.996	0.876	0.884	1.061	1.068	1.112	0.895	1.024
		FI	1.056	0.999	0.840	1.106	1.318	1.202	1.031	1.167
		PDO	0.964	0.804	0.910	1.036	0.922	1.062	0.817	0.943
Run-off-road crashes										
Multilane	Paved	Total	0.958	1.135	1.174	0.891	1.094	0.974	0.962	0.819
		FI	1.167	1.268	1.267	1.267	1.425	1.216	1.048	1.064
		PDO	0.928	1.168	1.241	0.731	0.987	0.917	0.999	0.747
Two-lane	Paved	Total	1.192	1.389	1.131	1.397	1.307	1.542	1.458	1.378
		FI	1.302	1.188	1.226	1.502	1.481	1.688	1.474	1.416
		PDO	1.110	1.581	1.058	1.318	1.168	1.430	1.451	1.355
	Unpaved	Total	1.107	1.064	1.089	1.201	1.335	1.280	1.046	1.183
		FI	1.150	1.167	0.828	1.241	1.405	1.232	1.114	1.265
		PDO	1.003	0.905	1.282	1.095	1.194	1.256	0.923	1.036
Drop-off-related crashes										
Multilane	Paved	Total	1.040	1.102	1.134	1.101	1.034	1.003	1.156	0.774
		FI	0.925	1.320	0.989	1.121	0.989	1.254	1.117	0.860
		PDO	1.156	0.874	1.275	1.075	1.075	0.741	1.188	0.683
Two-lane	Paved	Total	1.203	1.410	1.144	1.385	1.364	1.609	1.491	1.511
		FI	1.290	1.135	1.270	1.449	1.549	1.652	1.543	1.636
		PDO	1.111	1.746	1.001	1.312	1.154	1.564	1.429	1.368
	Unpaved	Total	1.129	1.035	1.133	1.240	1.397	1.409	1.194	1.303
		FI	1.217	1.212	0.818	1.186	1.426	1.409	1.345	1.393
		PDO	0.997	0.794	1.506	1.285	1.335	1.384	0.982	1.165

Table 14. Indiana SPF Calibration Factors

Roadway type	Shoulder type	Crash severity level	Yearly calibration factors					
			2003	2004	2005	2006	2007	2008
Total crashes								
Two-lane	Paved	Total	0.932	0.944	0.579	0.605	0.320	0.384
		FI	0.918	1.006	0.456	0.586	0.343	0.326
		PDO	0.943	0.936	0.616	0.615	0.317	0.402
	Unpaved	Total	1.268	1.011	0.629	0.556	0.365	0.265
		FI	0.914	1.002	0.471	0.472	0.287	0.182
		PDO	1.322	0.968	0.650	0.557	0.373	0.279
Run-off-road crashes								
Two-lane	Paved	Total	1.092	0.936	0.607	0.551	0.304	0.497
		FI	1.266	1.097	0.489	0.651	0.407	0.448
		PDO	1.074	0.911	0.713	0.535	0.268	0.558
	Unpaved	Total	1.002	0.863	0.479	0.363	0.279	0.177
		FI	0.850	1.041	0.503	0.446	0.232	0.154
		PDO	1.068	0.754	0.457	0.313	0.300	0.186
Drop-off-related crashes								
Two-lane	Paved	Total	0.994	0.946	0.646	0.431	0.431	0.690
		FI	0.729	0.722	0.362	0.434	0.290	0.290
		PDO	1.016	0.929	0.777	0.310	0.467	0.934
	Unpaved	Total	1.289	1.038	0.544	0.545	0.520	0.249
		FI	1.265	0.989	0.661	0.441	0.385	0.220
		PDO	1.298	1.066	0.459	0.613	0.610	0.267

4.3 Safety Evaluations

As discussed earlier in this section, four types of safety evaluations were performed as part of this study: a safety comparison of treatment and comparison sites in the period before resurfacing; an EB before-after evaluation; a cross-sectional analysis; and an analysis of shifts in the severity distribution from before to after resurfacing. The findings of these evaluations are presented below.

4.3.1 Safety Comparison of Treatment and Comparison Sites in the Period Before Resurfacing

An evaluation was conducted to compare the safety performance of treatment and comparison sites before resurfacing for specific states and roadway type/shoulder type combinations. This evaluation is critical to the interpretation of the safety differences between the treatment and comparison sites as an effect of the safety edge treatment. If the safety performance of the two types of sites differs in the period before resurfacing, this may influence the comparison of treatment and comparison sites in the period after resurfacing.

Initial comparisons were made by examination of scatter plots of crashes and traffic volumes (crashes per mile per year vs. lnAADT). Ideal plots would contain no discernable differences between treatment and comparison sites as well as no extreme points. Separation of the data points between the two groups may indicate a potential concern in the subsequent analyses. Also, if one group had systematically higher crash frequencies in the period before resurfacing, then the analysis for the period after resurfacing might need to account for this difference. Finally, large variation in crash frequencies for the same AADT values could also inhibit crash analysis of the treatment and comparison groups. Inspection of these plots with data from Year 3 (Appendix C) showed an improvement in the plots from Year 1 and Year 2.

Yearly total crash and target crash distributions were also present in box plots to review data consistency from year to year. Ideal plots would have approximately the same distribution for crashes each year within a given site type, as well as between site types. Additionally, potential concerns for the crash analysis to be performed may be identified if the period after resurfacing is also included. Specifically, a regression-to-the-mean or resurfacing effect may be identified.

Since crash frequencies are known to experience random variation around the mean or regression to the mean, the average over several years for the period before resurfacing should ideally be compared to the average of several years for the period after resurfacing. Therefore, if the after-period data is within the range of yearly crash means but numerically higher than the before period average, then safety analyses might show an increase in crash frequency due to the treatment (provided AADT growth was minimal). Conversely, if the after implementation year is lower than the before period average, then the treatment effect will be a decrease in crash frequency. Examination of these graphs indicated that the after period year was almost always higher than the average of the before years but within the range of variation in yearly crash totals for both types of treated sites.

The apparent increase in crashes was examined to determine if it could be attributed to resurfacing. A resurfacing effect occurs when the reference sites remain the same or decrease in crashes while the treatment and comparison sites both increase. This was observed in nearly all of the plots.

One additional potential problem was found in this analysis. One treatment site on a two-lane highway with paved shoulders in Georgia site doubled in crash frequency from the before to the after period. Subsequent investigation found that this site was reconstructed during the second year after resurfacing and, therefore, it was excluded from the safety analysis presented in this report.

Formal crash frequency comparisons of means between the treatment and comparison sites for the period before resurfacing were conducted for each state/roadway type/shoulder type combination and target crash type. Two types of comparisons were made, comparison of EB-adjusted expected crash frequencies and a comparison of observed crash frequencies. Both comparisons were performed using PROC GENMOD (a generalized linear model procedure), available in the SAS software package (*6*), assuming a negative binomial crash distribution. This procedure uses predictive modeling to test the means between the two treatment groups for statistical significance.

The results of these analyses are presented in Tables 15 and 16. For the EB-adjusted crash analysis, results are provided only for those roadway type/shoulder type combinations for which SPFs could be developed. However, all target crash types were considered as they can be estimated by the EB procedure. Regression coefficients with their standard errors are shown in the tables for each independent variable, including AADT and the treatment vs. comparison site effect. The significance and p-value for each effect are also presented. Blank rows in the tables represent models that did not converge.

Results from the analysis of EB-adjusted crash frequencies in Table 15 show that there tend to be significant differences between treatment and comparison site crash frequencies for Georgia sites with unpaved shoulders in the period before resurfacing. In these differences, comparison sites that had unpaved shoulders had lower crash rates than treatment sites. There also appears to be some evidence of differences in drop-off-related and run-off-road crashes for Georgia paved shoulder locations. Similarly, Indiana unpaved shoulder locations are different for drop-off-related crashes. These differences had treatment sites with lower crash rates.

Results from the analysis of observed crash frequencies somewhat confirmed the results of the EB-adjusted crashes. However, there tended to be fewer significant results and poorer fit of the models in general. This is to be expected since EB-adjusted crashes are smoothed by the SPF model predictions, which causes smaller differences and less variation, leading to more significant results. Differences between treatment and comparison sites were confirmed for Georgia unpaved shoulder locations and drop-off-related crashes for paved shoulder locations. Additionally, New York locations, not tested by EB-adjusted crashes, showed differences for run-off-road crashes. All other significant differences were associated with poor models.

It was also desirable to confirm the existence of a cause-and-effect chain leading from the frequency and height of pavement edge drop-offs to the likelihood of crashes. The drop-off height analysis reported in Section 3 indicated that two-lane highway sites with unpaved shoulders and the multilane highway sites in Georgia did not have significant differences in the proportion of high drop-offs and, therefore, should have non-significant differences in crash frequency in the period before resurfacing. This expectation was not entirely supported by crash analysis results. However, for cases in which there were significant differences, these differences were in the same direction as the drop-off analysis indicated. That is, if drop-offs were more prevalent, then the sites had more crashes and vice versa. Similarly, two-lane highway sites with paved shoulders in Georgia had comparison sites with a significantly higher probability of having more high drop-offs, and the crash analysis showed comparison sites have more crashes, although the result was not significant.

Table 15. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using EB-Adjusted Crash Frequencies

State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	AADT effect				Lane width effect				Treatment vs. comparison site effect				Dispersion parameter	R^2_{LR}%
						Coefficient	Standard error	p-value	Statistically significant?	Coefficient	Standard error	p-value	Statistically significant?	Coefficient	Standard error	p-value	Statistically significant?		
GA	Multilane	Paved	TOT	102	-3.965	0.572	0.143	0.001	Y					-0.497	0.452	0.272	N	0.237	31.4
			FI	102	-2.115	0.239	0.165	0.148	N					-0.391	0.394	0.322	N	0.031	9.4
			PDO	102	-5.926	0.740	0.172	0.001	Y					-0.531	0.525	0.312	N	0.282	35.3
			rorTOT	102	-5.253	0.559	0.179	0.002	Y					-0.149	0.191	0.434	N	0.010	5.9
			rorFI	102	-3.843	0.328	0.158	0.038	Y					-0.293	0.169	0.083	Y	0.010	22.2
			rorPDO	102	-7.761	0.757	0.189	0.001	Y					-0.043	0.239	0.856	N	0.010	8.1
			doTOT	102	-4.265	0.430	0.127	0.001	Y					-0.095	0.132	0.469	N	0.010	21.2
			doFI	102	-3.620	0.285	0.104	0.006	Y					-0.134	0.106	0.204	N	0.010	24.1
			doPDO	102	-6.240	0.569	0.172	0.001	Y					-0.060	0.177	0.734	N	0.010	19.1
	Two-lane	Paved	TOT	264	-12.086	1.475	0.089	0.000	Y					0.154	0.177	0.384	N	0.010	56.9
			FI	264	-11.367	1.306	0.099	0.000	Y					-0.104	0.129	0.420	N	0.010	33.5
			PDO	264	-13.244	1.534	0.095	0.000	Y					0.302	0.222	0.175	N	0.010	48.0
			rorTOT	264	-5.358	1.133	0.107	0.000	Y	-0.361	0.093	0.001	Y	-0.259	0.141	0.067	Y	0.010	25.3
			rorFI	264	-4.377	0.973	0.132	0.001	Y	-0.381	0.070	0.001	Y	-0.338	0.126	0.007	Y	0.010	5.2
			rorPDO	264	-7.053	1.173	0.100	0.000	Y	-0.314	0.128	0.014	Y	-0.190	0.167	0.255	N	0.010	15.9
			doTOT	264	-7.238	1.221	0.116	0.000	Y	-0.303	0.067	0.001	Y	-0.312	0.120	0.009	Y	0.010	19.0
			doFI	264	-6.870	1.207	0.124	0.000	Y	-0.366	0.102	0.000	Y	-0.369	0.158	0.020	Y	0.010	1.7
			doPDO	264	-10.155	1.290	0.105	0.000	Y	-0.189	0.107	0.078	Y	-0.169	0.123	0.171	N	0.010	12.1
		Unpaved	TOT	318	-8.117	1.001	0.098	0.000	Y					0.611	0.149	0.001	Y	0.010	61.2
			FI	318	-8.026	0.899	0.102	0.000	Y					0.237	0.137	0.084	Y	0.010	39.1
			PDO	318	-9.051	1.031	0.079	0.000	Y					0.902	0.180	0.001	Y	0.010	57.8
			rorTOT	318	-7.230	0.819	0.088	0.000	Y					0.358	0.159	0.024	Y	0.010	37.3
			rorFI	318	-6.816	0.703	0.077	0.000	Y					0.179	0.133	0.179	N	0.010	20.6
			rorPDO	318	-8.895	0.909	0.071	0.000	Y					0.574	0.208	0.006	Y	0.010	30.0
			doTOT	318	-7.444	0.801	0.084	0.000	Y					0.271	0.142	0.056	Y	0.010	29.7
			doFI	318	-6.545	0.636	0.085	0.001	Y					0.180	0.127	0.157	N	0.010	12.8
			doPDO	318	-10.351	1.026	0.107	0.000	Y					0.414	0.196	0.035	Y	0.010	21.4

[a] Crash types and severity levels:
TOT = total crashes (all severity levels combined)
FI = fatal–and–injury crashes
PDO = property–damage-only crashes
ror = run-off-road crashes
do = drop-off-related crashes
[b] At the 0.20 level.

Table 15. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using EB-Adjusted Crash Frequencies (Continued)

State	Roadway type	Shoulder type	Crash type and severity level	Number of site-years	Intercept	AADT effect				Lane width effect				Treatment vs. comparison site effect				Dispersion parameter	R^2_{LR}%
						Coefficient	Standard error	p-value	Statistically significant?	Coefficient	Standard error	p-value	Statistically significant?	Coefficient	Standard error	p-value	Statistically significant?		
IN	Two-lane	Paved	TOT	42	-10.904	1.409	0.056	0.000	Y					-0.517	0.307	0.092	Y	0.150	7.3
			FI	42	-21.302	2.546	0.222	0.000	Y					-1.076	0.338	0.001	Y	0.010	9.3
			PDO	42	-2.772	0.422	0.114	0.000	Y					-0.184	0.405	0.650	N	0.152	4.7
			rorTOT	42	-2.431	0.208	0.283	0.463	N					-0.054	0.208	0.793	N	0.010	23.8
			rorFI	42	-4.735	0.361	0.061	0.001	Y					-0.073	0.078	0.352	N	0.010	34.0
			rorPDO	42															
			doTOT	42															
			doFI	42	-5.918	0.391	0.059	0.001	Y					-0.269	0.159	0.090	Y	0.010	35.2
			doPDO	42															
		Unpaved	TOT	68	-0.578	0.787	0.231	0.001	Y	-0.506	0.117	0.001	Y	0.097	0.273	0.723	N	0.137	43.8
			FI	68	-1.688	0.470	0.141	0.001	Y	-0.312	0.061	0.001	Y	-0.063	0.165	0.701	N	0.010	15.9
			PDO	68	-1.128	0.932	0.264	0.000	Y	-0.584	0.141	0.001	Y	0.172	0.302	0.570	N	0.212	40.4
			rorTOT	68	0.889	0.588	0.208	0.005	Y	-0.585	0.103	0.001	Y	-0.045	0.219	0.837	N	0.010	34.6
			rorFI	68	-1.126	0.283	0.035	0.001	Y	-0.278	0.010	0.000	Y	-0.039	0.040	0.328	N	0.010	17.1
			rorPDO	68	0.902	0.879	0.321	0.006	Y	-0.838	0.174	0.001	Y	-0.015	0.323	0.964	N	0.010	35.7
			doTOT	68	-0.837	0.211	0.106	0.047	Y	-0.242	0.069	0.000	Y	-0.433	0.169	0.011	Y	0.010	5.1
			doFI	68	-1.842	0.139	0.056	0.013	Y	-0.190	0.036	0.001	Y	-0.246	0.092	0.008	Y	0.010	21.4
			doPDO	68	-1.212	0.259	0.161	0.108	Y	-0.285	0.107	0.008	Y	-0.565	0.258	0.028	Y	0.010	3.5

[a] Crash types and severity levels:
TOT = total crashes (all severity levels combined)
FI = fatal–and–injury crashes
PDO = property–damage-only crashes
ror = run-off-road crashes
do = drop-off-related crashes

[b] At the 0.20 level.

Table 16. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using Observed Crash Frequencies

State	Roadway type	Shoulder type	Crash type and severity level[a]	Number of site-years	Intercept	AADT effect: Coefficient	AADT effect: Standard error	AADT effect: p-value	AADT effect: Statistically significant[b]	Lane width effect: Coefficient	Lane width effect: Standard error	Lane width effect: p-value	Lane width effect: Statistically significant[b]	Treatment vs. comparison site effect: Coefficient	Treatment vs. comparison site effect: Standard error	Treatment vs. comparison site effect: p-value	Treatment vs. comparison site effect: Statistically significant[b]	Dispersion parameter	R^2_{LR}%
GA	Multilane	Paved	TOT	102	-9.014	1.128	0.282	0.000	Y					-0.878	0.505	0.082	Y	0.378	27.7
			FI	102	-7.293	0.812	0.288	0.005	Y					-0.826	0.516	0.109	N	0.338	10.1
			PDO	102	-10.881	1.286	0.321	0.000	Y					-0.885	0.527	0.093	Y	0.505	27.3
			rorTOT	102	-7.749	0.822	0.268	0.002	Y					-0.295	0.225	0.188	N	0.015	15.0
			rorFI	102	-7.005	2.654	0.660	0.288	Y					-0.547	0.259	0.035	Y	0.010	5.6
			rorPDO	102	-9.207	3.372	0.911	0.353	Y					-0.119	0.282	0.672	N	0.010	16.2
			doTOT	102	-8.374	2.175	0.844	0.229	Y					-0.355	0.180	0.048	Y	0.010	11.9
			doFI	102	-8.785	2.656	0.809	0.287	Y					-0.442	0.221	0.046	Y	0.010	5.0
			doPDO	102	-9.387	3.466	0.884	0.364	Y					-0.304	0.272	0.264	N	0.010	7.6
	Two-lane	Paved	TOT	264	-8.045	0.982	0.130	0.000	Y					0.222	0.176	0.207	N	0.247	35.7
			FI	264	-7.646	0.852	0.143	0.000	Y					-0.121	0.152	0.426	N	0.018	21.3
			PDO	264	-10.106	1.147	0.139	0.000	Y					0.447	0.200	0.025	Y	0.436	30.8
			rorTOT	264	-3.346	0.666	0.121	0.000	Y	-0.220	0.161	0.172	Y	-0.231	0.206	0.261	N	0.166	13.9
			rorFI	264	-1.188	0.465	0.156	0.003	Y	-0.303	0.161	0.059	Y	-0.593	0.229	0.010	Y	0.073	7.2
			rorPDO	264	-8.299	0.834	0.118	0.000	Y					0.110	0.203	0.587	N	0.360	10.8
			doTOT	264	-6.541	0.673	0.173	0.000	Y					-0.297	0.173	0.086	Y	0.177	10.3
			doFI	264	-1.063	0.414	0.202	0.040	Y	-0.300	0.170	0.077	Y	-0.752	0.249	0.003	Y	0.173	5.7
			doPDO	264	-10.600	1.038	0.204	0.000	Y					-0.016	0.223	0.942	N	0.156	9.9
		Unpaved	TOT	318	-8.615	1.059	0.104	0.000	Y					0.610	0.174	0.000	Y	0.389	35.9
			FI	318	-8.473	0.940	0.097	0.000	Y					0.258	0.177	0.143	N	0.318	21.3
			PDO	318	-9.950	1.148	0.119	0.000	Y					0.864	0.197	0.000	Y	0.419	34.3
			rorTOT	318	-7.022	0.774	0.106	0.000	Y					0.441	0.194	0.023	Y	0.309	19.4
			rorFI	318	-7.358	0.740	0.109	0.000	Y					0.226	0.220	0.304	N	0.487	9.7
			rorPDO	318	-8.611	0.874	0.150	0.000	Y					0.653	0.228	0.004	Y	0.385	16.8
			doTOT	318	-7.106	0.736	0.132	0.000	Y					0.397	0.212	0.061	Y	0.247	15.6
			doFI	318	-6.937	0.645	0.139	0.000	Y					0.270	0.245	0.272	N	0.548	6.9
			doPDO	318	-9.469	0.922	0.188	0.000	Y					0.554	0.252	0.028	Y	0.361	12.5

[a] Crash types and severity levels:
TOT = total crashes (all severity levels combined)
FI = fatal–and–injury crashes
PDO = property–damage-only crashes
ror = run-off-road crashes
do = drop-off-related crashes
[b] At the 0.20 significance level.

Table 16. Evaluation of Treatment vs. Comparison Site Effect for the Period Before Resurfacing Using Observed Crash Frequencies (Continued)

						AADT effect				Lane width effect				Treatment vs. comparison site effect					
State	Roadway type	Shoulder type	Crash type and severity level[a]	Number of site-years	Intercept	Coefficient	Standard error	p-value	Statistically significant?	Coefficient	Standard error	p-value	Statistically significant[b]	Coefficient	Standard error	p-value	Statistically significant[b]	Dispersion parameter	R^2_{LR}%
IN	Two-lane	Paved	TOT	42	-3.824	0.588	0.250	0.019	Y					-0.380	0.364	0.296	N	0.416	6.6
			FI	42	-7.523	0.850	0.606	0.161	N					-0.842	0.533	0.114	N	0.629	7.9
			PDO	42	-3.076	0.465	0.235	0.048	Y					-0.205	0.356	0.565	N	0.369	4.1
			rorTOT	42	-6.756	0.736	0.546	0.178	N					-0.468	0.396	0.237	N	0.446	5.1
			rorFI	42	-2.953	4.414	0.188	0.515	N					-0.830	0.457	0.069	Y	0.010	6.0
			rorPDO	42	-8.070	0.815	0.589	0.167	N					-0.092	0.432	0.831	N	0.461	5.0
			doTOT	42	-13.860	1.420	1.212	0.241	N					-0.996	0.503	0.048	Y	0.478	6.0
			doFI	42															0.0
			doPDO	42	-23.901	2.478	0.959	0.010	Y					-0.477	0.529	0.368	N	0.010	11.9
		Unpaved	TOT	68	-0.761	0.918	0.248	0.000	Y	-0.587	0.140	0.000	Y	0.188	0.297	0.525	N	0.435	35.8
			FI	68	-0.041	0.732	0.347	0.035	Y	-0.640	0.225	0.005	Y	-0.050	0.347	0.884	N	0.093	23.4
			PDO	68	-1.612	0.998	0.270	0.000	Y	-0.594	0.155	0.000	Y	0.269	0.304	0.377	N	0.527	31.5
			rorTOT	68	1.418	0.806	0.316	0.011	Y	-0.783	0.200	0.000	Y	-0.068	0.331	0.838	N	0.221	34.7
			rorFI	68	1.478	3.119	0.435	0.358	N	-0.608	0.212	0.004	Y	-0.268	0.340	0.431	N	0.010	18.7
			rorPDO	68	0.475	1.120	0.398	0.005	Y	-0.974	0.313	0.002	Y	0.091	0.365	0.804	N	0.377	29.2
			doTOT	68	1.029	0.101	0.386	0.794	N	-0.312	0.246	0.204	N	-1.107	0.596	0.063	Y	0.010	21.7
			doFI	68															0.0
			doPDO	68	-4.194	0.270	0.560	0.630	N					-1.090	0.699	0.119	N	0.584	6.4
NY	Two-lane	Paved	TOT	36	-5.328	0.674	0.085	0.000	Y					0.127	0.182	0.484	N	0.486	24.9
			FI	36	-6.943	0.766	0.113	0.000	Y					0.308	0.172	0.074	Y	0.674	19.3
			PDO	36	-5.467	0.625	0.083	0.000	Y					-0.030	0.204	0.884	N	0.813	15.7
			rorTOT	36	-4.846	0.480	0.085	0.000	Y					0.577	0.140	0.000	Y	0.243	19.6
			rorFI	36	-5.333	0.486	0.122	0.000	Y					0.643	0.175	0.000	Y	0.410	14.4
			rorPDO	36	-5.784	0.372	0.467	0.048	Y					0.475	0.105	0.000	Y	0.010	13.0
			doTOT	36															
			doFI	36															
			doPDO	36															

[a] Crash types and severity levels:
TOT = total crashes (all severity levels combined)
FI = fatal–and–injury crashes
PDO = property–damage-only crashes
ror = run-off-road crashes
do = drop-off-related crashes

[b] At the 0.20 significance level.

Results for Indiana sites on two-lane highways with paved shoulders were consistent with the results of the analysis of drop-off measurements, but the results for Indiana sites for two-lane highways with unpaved shoulders were not consistent with the analysis of drop-off measurements.

Overall, the treatment and comparison sites showed similar crash frequencies for paved shoulder sites in the period before resurfacing. By contrast, there were some statistically significant differences in crash frequencies between treatment and comparison sites for unpaved shoulders during the period before resurfacing. It should be noted that the period before resurfacing in Indiana for which crash data were available was only two years in duration, in comparison to six years for the period before resurfacing in Georgia. Thus, the variability of the Indiana crash frequencies would be expected to be higher. In most cases (with one exception noted above), the differences in crash frequencies between treatment and comparison sites were similar to the differences in proportions of extreme drop-off heights for the period before resurfacing.

4.3.2 Before-After Evaluation Using the EB Method

An observational before-after evaluation was conducted using the EB method to estimate the safety effectiveness of the safety edge treatment. Separate before-after evaluations were conducted for resurfacing projects with safety edge (treatment sites) and resurfacing projects without the safety edge (comparison sites). The ratio in these results was used to estimate the effect of the safety edge treatment.

All crash severity levels for total crashes, run-off-road crashes, and drop-off-related crashes were evaluated. The study period before resurfacing for these evaluations was the four-year period from 2001 to 2004. The study period after resurfacing was the three-year period 2006 to 2008. The entire year in which resurfacing was performed (2005) was excluded from the evaluation. The rationale for excluding crashes during the construction year is that it takes time for drivers to adjust to the new driving conditions, and so the transition period during which drivers become adjusted to the resurfaced roadway is not necessarily representative of the long-term safety performance of the site. All of the crash data used in the evaluation were for complete calendar years, so that there would be no opportunity for seasonal biases to affect the evaluation results.

The EB procedure was programmed and executed in the SAS software package (*5*). Effectiveness estimates and their precision estimates, along with their statistical significance, are presented for specific crash types in Tables 17 through 25.

The safety edge effect shown in the results tables is the ratio between the before-to-after change in crash frequency for the treatment sites and the before-to-after change in crash frequency for the comparison sites. This formulation of the safety effect was derived from the multiplicative nature of accident modification factors (AMFs):

$$\mathrm{AMF}_{Resurfacing+SafetyEdge} = \mathrm{AMF}_{Resurfacing}\mathrm{AMF}_{SafetyEdge} \qquad (3)$$

or

$$AMF_{SafetyEdge} \frac{AMF_{Resurfacing+SafetyEdge}}{AMF_{Resurfacing}} = \frac{AMF_{Treatment}}{AMF_{Comparison}} \quad (4)$$

The before-to-after percent change in crash frequency can be converted to an AMF for this calculation by dividing by 100 and adding a value of one. Similarly, the final AMF for the safety edge can be converted back to a percent change by subtracting the ratio from one and multiplying by 100. When the increase in crashes with resurfacing was greater at the comparison sites than at the treatment sites, an indication that the safety edge treatment was effective, the safety edge effect is shown in the tables as a positive value. A precision estimate of the ratio was calculated and used to generate a confidence interval of the ratio. Confidence intervals excluding the value one indicate statistical significance. For instance, the safety edge effect for Georgia two-lane roadways with paved shoulders shown in Table 17 is calculated by first converting the before-to-after changes to AMFs and then taking the ratio: (1+13.12/100)/(1+22.60/100)=1.1312/1.2260=0.927. This AMF represents a (1-0.927)*100=7.73 percent decrease in accidents. Since both confidence intervals (i.e., 7.73±(9.60)*1.645 and 7.73±(9.60)*1.96, where 1.645 and 1.96 are critical confidence level values) contain the value one, the estimate of the safety edge effect is not significant.

The EB results indicate that for all two-lane sites in Georgia and Indiana combined the safety edge effect was 5.7 percent for total crashes, 6.3 percent for run-off-road crashes, and 5.6 percent for drop-off-related crashes. While none of these results is statistically significant they do show a small consistent benefit of the provision of the safety edge on rural two-lane highways.

When the results are examined separately for the two shoulder types, sites with paved shoulders having widths of 1.2 m (4 ft) or less and sites with unpaved shoulders, the paved shoulder sites show more benefit of the use of the safety edge than for unpaved shoulders. The safety edge effect for sites with paved shoulders is 9.5 percent for total crashes, 14.2 percent for run-off-road crashes, and 12.6 percent for drop-off-related crashes. The results for run-off road crashes are statistically significant at the 10 percent significance level, but the result for total crashes and drop-off related crashes are not statistically significant. For sites with unpaved shoulders the safety edge effect was 6.5 percent for total crashes, 4.8 percent for run-off-road crashes and 4.5 percent for drop-off-related crashes. None of these results is significant.

This result is somewhat unexpected, as one would expect that there are larger benefits from the use of the safety edge treatment on highways with unpaved shoulders, since potential drop-offs at such sites are closer to the travel lanes than for highways with paved shoulders and are, therefore, expected to be driven over more frequently. However, the sites with unpaved shoulders in both states have much lower ADTs than the sites with paved shoulders and the lower numbers of crashes in both the before and after resurfacing periods undoubtedly affected the effectiveness estimates.

In considering the states individually Georgia sites showed a safety edge effect of 6.8 percent for total crashes, 7.9 percent for run-off-road crashes and 6.6 percent for drop-off-related crashes. None of the results were statistically significant. Indiana sites had safety edge effects of -0.2 percent for total crashes, -13.5 percent for run-off-road crashes, and -19.7 percent for

Table 17. Before-After Empirical Bayes Evaluation Results for Total Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing: Percent change	Direction	Standard error (%)	Statistically significant?: 5% level	10% level	Safety edge effect: Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	1.804	13.123	Increase	7.276	N	Y	7.732	Decrease	9.596	N	N
			C	19	2.262	22.602	Increase	9.993	Y	Y					
		Unpaved	T	22	2.246	-13.562	Decrease	6.038	Y	Y	11.361	Decrease	8.467	N	N
			C	31	0.389	-2.483	Decrease	6.376	N	N					
		Combined	T	47	0.143	-0.670	Decrease	4.697	N	N	6.817	Decrease	6.459	N	N
			C	50	1.217	6.597	Increase	5.421	N	N					
IN	Two-lane	Paved	T	14	0.047	0.567	Increase	12.167	N	N	15.524	Decrease	14.422	N	N
			C	7	1.333	19.048	Increase	14.293	N	N					
		Unpaved	T	16	1.524	29.925	Increase	19.639	N	N	-26.942	Increase	24.027	N	N
			C	18	0.201	2.350	Increase	11.691	N	N					
		Combined	T	30	1.000	10.456	Increase	10.454	N	N	-0.235	Increase	12.622	N	N
			C	25	1.120	10.197	Increase	9.104	N	N					
GA & IN	Two-lane	Paved	T	39	1.601	10.027	Increase	6.262	N	N	9.485	Decrease	8.009	N	N
			C	26	2.628	21.556	Increase	8.203	Y	Y					
		Unpaved	T	38	1.311	-7.657	Decrease	5.842	N	N	6.516	Decrease	7.910	N	N
			C	49	0.218	-1.221	Decrease	5.604	N	N					
		Combined	T	77	0.360	1.546	Increase	4.293	N	N	5.674	Decrease	5.737	N	N
			C	75	1.642	7.654	Increase	4.662	N	N					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 18. Before-After Empirical Bayes Evaluation Results for Fatal-and-Injury Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing: Percent change	Direction	Standard error (%)	Statistically significant? 5% level	10% level	Safety edge effect: Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	1.592	19.899	Increase	12.499	N	N	10.959	Decrease	13.779	N	N
			C	19	2.244	34.656	Increase	15.446	Y	Y					
		Unpaved	T	22	0.232	2.761	Increase	11.887	N	N	-15.555	Increase	17.687	N	N
			C	31	1.243	-11.072	Decrease	8.907	N	N					
		Combined	T	47	1.346	11.647	Increase	8.651	N	N	-5.982	Increase	11.462	N	N
			C	50	0.676	5.345	Increase	7.905	N	N					
IN	Two-lane	Paved	T	14	0.736	-18.579	Decrease	25.239	N	N	44.993	Decrease	21.492	Y	Y
			C	7	1.359	48.020	Increase	35.335	N	N					
		Unpaved	T	16	1.340	-35.945	Decrease	26.829	N	N	43.548	Decrease	26.137	N	N
			C	18	0.598	13.469	Increase	22.521	N	N					
		Combined	T	30	1.339	-24.947	Decrease	18.633	N	N	40.939	Decrease	17.167	Y	Y
			C	25	1.403	27.078	Increase	19.294	N	N					
GA & IN	Two-lane	Paved	T	39	1.295	14.685	Increase	11.337	N	N	16.528	Decrease	11.919	N	N
			C	26	2.633	37.393	Increase	14.199	Y	Y					
		Unpaved	T	38	0.087	-0.961	Decrease	11.012	N	N	-6.361	Increase	15.147	N	N
			C	49	0.827	-6.884	Decrease	8.328	N	N					
		Combined	T	77	0.924	7.328	Increase	7.93	N	N	1.667	Decrease	9.780	N	N
			C	75	1.246	9.148	Increase	7.341	N	N					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 19. Before-After Empirical Bayes Evaluation Results for Property-Damage-Only Crashes

						Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	0.975	9.276	Increase	9.511	N	N	2.554	Decrease	15.183	N	N
			C	19	0.837	12.140	Increase	14.502	N	N					
		Unpaved	T	22	2.886	-20.980	Decrease	7.271	Y	Y	24.281	Decrease	10.078	Y	Y
			C	31	0.437	4.359	Increase	9.963	N	N					
		Combined	T	47	1.150	-6.764	Decrease	5.881	N	N	13.201	Decrease	8.607	N	N
			C	50	0.899	7.416	Increase	8.249	N	N					
In	Two-lane	Paved	T	14	0.287	4.045	Increase	14.108	N	N	6.579	Decrease	18.450	N	N
			C	7	0.710	11.372	Increase	16.024	N	N					
		Unpaved	T	16	1.898	47.501	Increase	25.033	N	Y	-50.902	Increase	33.486	N	N
			C	18	0.160	-2.254	Decrease	14.046	N	N					
		Combined	T	30	1.449	18.175	Increase	12.540	N	N	-12.894	Increase	16.531	N	N
			C	25	0.440	4.678	Increase	10.631	N	N					
GA & IN	Two-lane	Paved	T	39	0.995	7.860	Increase	7.901	N	N	3.845	Decrease	11.632	N	N
			C	26	1.127	12.173	Increase	10.803	N	N					
		Unpaved	T	38	1.469	-10.599	Decrease	7.215	N	N	12.795	Decrease	9.898	N	N
			C	49	0.309	2.518	Increase	8.150	N	N					
		Combined	T	77	0.185	-0.995	Decrease	5.364	N	N	7.100	Decrease	7.601	N	N
			C	75	1.007	6.572	Increase	6.529	N	N					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 20. Before-After Empirical Bayes Evaluation Results for Total Run-off-Road Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
						Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	3.375	27.777	Increase	8.230	Y	Y	13.721	Decrease	9.010	N	N
			C	19	3.956	48.097	Increase	12.158	Y	Y					
		Unpaved	T	22	0.102	0.718	Increase	7.049	N	N	9.080	Decrease	8.652	N	N
			C	31	1.487	10.777	Increase	7.248	N	N					
		Combined	T	47	2.594	14.006	Increase	5.400	Y	Y	7.872	Decrease	6.406	N	N
			C	50	3.766	23.747	Increase	6.306	Y	Y					
IN	Two-lane	Paved	T	14	3.152	63.675	Increase	20.201	Y	Y	8.183	Decrease	15.844	N	N
			C	7	3.639	78.263	Increase	21.505	Y	Y					
		Unpaved	T	16	3.408	105.593	Increase	30.982	Y	Y	-46.895	Increase	27.796	N	Y
			C	18	2.502	39.959	Increase	15.968	Y	Y					
		Combined	T	30	4.573	78.116	Increase	17.083	Y	Y	-13.484	Increase	14.389	N	N
			C	25	4.391	56.952	Increase	12.969	Y	Y					
GA & IN	Two-lane	Paved	T	39	4.522	34.710	Increase	7.675	Y	Y	14.177	Decrease	7.593	N	Y
			C	26	5.351	56.962	Increase	10.645	Y	Y					
		Unpaved	T	38	1.631	11.534	Increase	7.071	N	N	4.786	Decrease	8.094	N	N
			C	49	2.581	17.140	Increase	6.640	Y	Y					
		Combined	T	77	4.496	23.514	Increase	5.230	Y	Y	6.315	Decrease	5.654	N	N
			C	75	5.576	31.840	Increase	5.710	Y	Y					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 21. Before-After Empirical Bayes Evaluation Results for Fatal-and-Injury Run-Off-Road Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
						Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	3.036	46.712	Increase	15.384	Y	Y	19.175	Decrease	12.659	N	N
			C	19	3.856	81.517	Increase	21.142	Y	Y					
		Unpaved	T	22	1.891	28.134	Increase	14.877	N	Y	-18.058	Increase	18.139	N	N
			C	31	0.784	8.535	Increase	10.892	N	N					
		Combined	T	47	3.529	37.878	Increase	10.733	Y	Y	-3.609	Increase	11.192	N	N
			C	50	3.295	33.075	Increase	10.037	Y	Y					
IN	Two-lane	Paved	T	14	0.086	-2.553	Decrease	29.761	N	N	46.332	Decrease	20.632	Y	Y
			C	7	1.931	81.574	Increase	42.252	N	Y					
		Unpaved	T	16	0.140	6.109	Increase	43.637	N	N	-12.464	Increase	51.101	N	N
			C	18	0.309	-5.651	Decrease	18.313	N	N					
		Combined	T	30	0.018	0.440	Increase	24.694	N	N	16.402	Decrease	23.965	N	N
			C	25	1.137	20.146	Increase	17.714	N	N					
GA & IN	Two-lane	Paved	T	39	2.877	39.851	Increase	13.853	Y	Y	23.123	Decrease	11.053	Y	Y
			C	26	4.323	81.916	Increase	18.950	Y	Y					
		Unpaved	T	38	1.877	26.499	Increase	14.120	N	Y	-20.037	Increase	17.137	N	N
			C	49	0.573	5.383	Increase	9.388	N	N					
		Combined	T	77	3.407	33.764	Increase	9.911	Y	Y	-2.622	Increase	10.228	N	N
			C	75	3.469	30.346	Increase	8.748	Y	Y					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 22. Before-After Empirical Bayes Evaluation Results for Property-Damage-Only Run-Off-Road Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing: Percent change	Direction	Standard error (%)	Statistically significant? 5% level	10% level	Safety edge effect: Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	1.821	18.575	Increase	10.200	N	Y	5.160	Decrease	14.498	N	N
			C	19	1.587	25.026	Increase	15.770	N	N					
		Unpaved	T	22	1.286	-10.527	Decrease	8.185	N	N	20.225	Decrease	10.451	N	Y
			C	31	1.158	12.156	Increase	10.494	N	N					
		Combined	T	47	0.535	3.462	Increase	6.472	N	N	11.524	Decrease	8.673	N	N
			C	50	1.929	16.938	Increase	8.779	N	Y					
IN	Two-lane	Paved	T	14	3.154	82.392	Increase	26.120	Y	Y	-3.538	Increase	21.327	N	N
			C	7	2.922	76.160	Increase	26.061	Y	Y					
		Unpaved	T	16	3.396	131.099	Increase	38.606	Y	Y	-31.229	Increase	30.365	N	N
			C	18	2.699	76.104	Increase	28.193	Y	Y					
		Combined	T	30	4.549	99.719	Increase	21.920	Y	Y	-12.878	Increase	17.414	N	N
			C	25	3.999	76.934	Increase	19.240	Y	Y					
GA & IN	Two-lane	Paved	T	39	3.323	32.288	Increase	9.718	Y	Y	7.374	Decrease	11.235	N	N
			C	26	3.108	42.820	Increase	13.778	Y	Y					
		Unpaved	T	38	0.657	5.574	Increase	8.485	N	N	16.029	Decrease	9.550	N	N
			C	49	2.548	25.727	Increase	10.096	Y	Y					
		Combined	T	77	2.976	19.201	Increase	6.452	Y	Y	10.162	Decrease	7.404	N	N
			C	75	3.995	32.684	Increase	8.181	Y	Y					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 23. Before-After Empirical Bayes Evaluation Results for Total Drop-Off-Related Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing: Percent change	Direction	Standard error (%)	Statistically significant? 5% level	10% level	Safety edge effect: Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	3.817	32.758	Increase	8.582	Y	Y	10.293	Decrease	9.405	N	N
			C	19	3.930	47.991	Increase	12.210	Y	Y					
		Unpaved	T	22	0.591	4.334	Increase	7.328	N	N	9.130	Decrease	8.698	N	N
			C	31	1.970	14.817	Increase	7.522	N	Y					
		Combined	T	47	3.250	18.272	Increase	5.623	Y	Y	6.603	Decrease	6.522	N	N
			C	50	4.115	26.633	Increase	6.472	Y	Y					
IN	Two-lane	Paved	T	14	3.681	86.217	Increase	23.425	Y	Y	8.759	Decrease	15.949	N	N
			C	7	4.202	104.093	Increase	24.772	Y	Y					
		Unpaved	T	16	4.374	193.003	Increase	44.122	Y	Y	-79.564	Increase	34.036	Y	Y
			C	18	3.357	63.175	Increase	18.820	Y	Y					
		Combined	T	30	5.509	117.38	Increase	21.305	Y	Y	-19.733	Increase	15.389	N	N
			C	25	5.386	81.554	Increase	15.141	Y	Y					
GA & IN	Two-lane	Paved	T	39	5.191	42.320	Increase	8.153	Y	Y	12.586	Decrease	7.803	N	N
			C	26	5.657	62.812	Increase	11.104	Y	Y					
		Unpaved	T	38	2.489	18.854	Increase	7.574	Y	Y	4.455	Decrease	8.189	N	N
			C	49	3.450	24.396	Increase	7.070	Y	Y					
		Combined	T	77	5.564	31.039	Increase	5.578	Y	Y	5.587	Decrease	5.739	N	N
			C	75	6.428	38.794	Increase	6.035	Y	Y					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 24. Before-After Empirical Bayes Evaluation Results for Fatal-and-Injury Drop-Off-Related Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing			Statistically significant?		Safety edge effect				
						Percent change	Direction	Standard error (%)	5% level	10% level	Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	3.082	48.356	Increase	15.691	Y	Y	15.135	Decrease	13.441	N	N
			C	19	3.639	74.815	Increase	20.560	Y	Y					
		Unpaved	T	22	2.068	31.810	Increase	15.383	Y	Y	-18.357	Increase	18.246	N	N
			C	31	1.014	11.366	Increase	11.214	N	N					
		Combined	T	47	3.683	40.587	Increase	11.019	Y	Y	-5.202	Increase	11.444	N	N
			C	50	3.317	33.635	Increase	10.139	Y	Y					
IN	Two-lane	Paved	T	14	1.727	120.288	Increase	69.662	N	Y	42.488	Decrease	22.855	N	Y
			C	7	3.073	283.030	Increase	92.115	Y	Y					
		Unpaved	T	16	1.038	77.468	Increase	74.600	N	N	38.503	Decrease	28.727	N	N
			C	18	3.208	188.581	Increase	58.789	Y	Y					
		Combined	T	30	2.037	105.168	Increase	51.641	Y	Y	36.972	Decrease	18.615	N	Y
			C	25	4.473	225.519	Increase	50.414	Y	Y					
GA & IN	Two-lane	Paved	T	39	3.473	53.546	Increase	15.419	Y	Y	21.596	Decrease	11.453	N	Y
			C	26	4.604	95.839	Increase	20.818	Y	Y					
		Unpaved	T	38	2.255	34.086	Increase	15.115	Y	Y	-5.230	Increase	15.186	N	N
			C	49	2.381	27.422	Increase	11.516	Y	Y					
		Combined	T	77	4.106	44.481	Increase	10.833	Y	Y	4.676	Decrease	9.672	N	N
			C	75	4.980	51.568	Increase	10.356	Y	Y					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Table 25. Before-After Empirical Bayes Evaluation Results for Property-Damage-Only Drop-Off-Related Crashes

State	Roadway type	Shoulder type	Site type	Number of sites	Odds ratio	Change in crash frequency from before to after resurfacing: Percent change	Direction	Standard error (%)	Statistically significant?: 5% level	10% level	Safety edge effect: Effect (%)	Direction	Standard error (%)	5% level	10% level
GA	Two-lane	Paved	T	25	2.281	24.794	Increase	10.870	Y	Y	2.550	Decrease	15.169	N	N
			C	19	1.698	28.059	Increase	16.524	N	N					
		Unpaved	T	22	0.826	-7.063	Decrease	8.556	N	N	20.631	Decrease	10.466	N	Y
			C	31	1.550	17.095	Increase	11.032	N	N					
		Combined	T	47	1.194	8.149	Increase	6.827	N	N	10.829	Decrease	8.786	N	N
			C	50	2.307	21.283	Increase	9.224	Y	Y					
IN	Two-lane	Paved	T	14	3.242	81.224	Increase	25.055	Y	Y	-2.553	Increase	20.262	N	N
			C	7	3.085	76.713	Increase	24.863	Y	Y					
		Unpaved	T	16	4.122	216.618	Increase	52.557	Y	Y	-131.652	Increase	50.289	Y	Y
			C	18	1.922	36.678	Increase	19.087	N	Y					
		Combined	T	30	5.032	118.845	Increase	23.618	Y	Y	-40.967	Increase	20.594	N	Y
			C	25	3.600	55.246	Increase	15.347	Y	Y					
GA & IN	Two-lane	Paved	T	39	3.695	37.481	Increase	10.143	Y	Y	5.319	Decrease	11.529	N	N
			C	26	3.217	45.205	Increase	14.052	Y	Y					
		Unpaved	T	38	1.390	12.718	Increase	9.148	N	N	7.890	Decrease	10.369	N	N
			C	49	2.330	22.373	Increase	9.601	Y	Y					
		Combined	T	77	3.730	25.534	Increase	6.845	Y	Y	4.435	Decrease	7.789	N	N
			C	75	3.926	31.360	Increase	7.988	Y	Y					

* Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

drop-off-related crashes. The negative results are not statistically significant at the 10 percent significance level. The results for Indiana sites were affected by very low numbers of crashes in the before period.

Overall results for the EB evaluation are summarized in Table 26 and compared to interim results obtained from analyses conducted one and two years after resurfacing. The analysis for data including three years after resurfacing, presented in this section of the report, includes additional comparisons because shoulder types and the two states were combined and compared. Fifty-six of the 81 results for Year 3 evaluation showed positive safety edge effects; however, only 11 of these positive safety effects were statistically significant. While 25 of the observed effects were negative, e.g., comparison sites had fewer crashes than treatment sites, only 4 of these results were statistically significant.

The magnitude of the effects was also changed with the addition of the Year 3 data. The safety effects from the Year 3 evaluation were smaller and less variable than the Year 1 or Year 2 results . The overall impact of the safety edge was expected to be small, since drop-off-related crashes were usually only a small percentage of the total non-intersection crashes on rural roads. The Year 3 results presented above follow this trend and therefore are considered more reliable than the earlier results. However, in some cases the smaller magnitude of the safety edge effect does make it more difficult for effect to be shown as statistically significant.

Table 26. Summary of Safety Effects From Year 3, Year 2 and Year 1 Results for Before-After Empirical Bayes Safety Evaluations

		Number of cases		
Direction of safety effect	Statistically significant safety effect?	Year 3 analysis results	Year 2 analysis results	Year 1 analysis results
Positive	Y	11	8	2
Positive	N	45	14	13
Negative	Y	4	7	6
Negative	N	21	7	15
		81	36	36

Total crashes on all sites mainly increased; some of this increase may be due to a resurfacing effect that was very evident in the Year 1 results, but less so in later years.

The Year 3 evaluation results presented above vary in magnitude and statistical significance. The overall evaluation results for total crashes in Georgia and Indiana combined show an average safety edge treatment effect of 5.7 percent. In other words, the sites treated with the safety edge appear to have lower crash frequencies after resurfacing than sites not treated with the safety edge. Although not statistically significant, this appears to be the most appropriate overall effectiveness measure for the safety edge treatment from the EB evaluation. The lack of statistical significance for this result is not surprising given the small magnitude of the effect.

Two trends were evident in the EB analysis of run-off-road and drop-off-related crashes. First, the safety edge treatment generally appears to have a positive effect on safety for all site types except for sites with unpaved shoulders in Indiana. This variability in results has not yet been fully explained. Second, however, the negative safety edge effects for Indiana sites with unpaved shoulders may be explained by low frequencies of drop-off-related crashes on comparison sites in the period before resurfacing. The safety edge effect was statistically significant only for Indiana sites with unpaved shoulders (negative effect).

Georgia sites with paved shoulders showed safety edge treatment effects of approximately 14 percent for run-off-road and10 percent for drop-off-related crashes. Indiana sites with unpaved shoulders had safety edge effects of −31 to −47 and −45 to −80 percent for run-off-road and drop-of-related crashes, respectively, and these effects were statistically significant. When data from both states were combined, the safety edge treatment effects for paved shoulders were 14 and 12.6 percent for run-off-road and drop-off-related crashes, respectively. The effect for run-off-road crashes was statistically significant at the 10 percent significance level. The treatment effects for sites with unpaved shoulders were 5 and 4.5 percent for run-off-road and drop-off-related crashes, respectively. These small non-significant effects are probably influenced strongly by Indiana sites with unpaved shoulders.

The results for run-off-road and drop-off-related crashes are larger than the effects for total crashes in absolute magnitude, but vary in sign and statistical significance. These evaluation results for run-off-road and drop-off-related crashes appear less stable, and thus less reliable, than the results for total crashes. Although not statistically significant, the single most reliable estimate of the effectiveness of the safety edge treatment is the 5.7 percent reduction in total crashes observed for two-lane highways in the combined data for sites with both paved and unpaved shoulders in both Georgia and Indiana (see the last row in Table 17).

There are several potential biases and limitations that may influence these results. Specifically, these potential biases and limitations include:

- there were some observed differences between treatment and comparison sites for the period before resurfacing (see discussions in Sections 3.1 and 4.3.1) which could confound the analysis results.
- the sites with unpaved shoulders, where the safety edge treatment would be expected to be most effective, also had the lowest crash frequencies; this increased the variability in the data and made the statistical test less powerful.

4.3.3 Cross-Sectional Analysis

A cross-sectional evaluation of the crash data for the period after resurfacing at the treatment and comparison sites was conducted to directly compare their safety performance. This cross-sectional analysis is analogous to the analysis of safety differences for the period before resurfacing reported in Section 4.3.1, but serves a different purpose. In this cross-sectional analysis, any observed difference in safety performance between the treatment and comparison sites is interpreted as an effect of the safety edge treatment. This interpretation should be made cautiously because, as noted in Sections 3 and 4.3.1 of this report, there are other differences between the treatment and comparison sites that may affect the comparison.

The cross-sectional comparison of data for the period after resurfacing was conducted using analysis of covariance, which was used to assess the statistical significance of the treatment vs. comparison site effect. This analysis was conducted for each state/roadway type/shoulder type combination with PROC GENMOD in the SAS software package (*4*). Traffic volume and site type (treatment vs. comparison) were the main factors of interest in the analysis. Lane width was also considered, but was not found to be statistically significant. The analysis was conducted with the same negative binomial modeling techniques described in the discussion of SPFs in Section 4.2 of this report.

The safety edge treatment effect and its standard error were calculated for each target crash type and with adjusted for any covariates. The results are presented in Table 27. The significance and p-value for the treatment vs. comparison site effects are also provided.

Where blank lines are shown in the table, the regression model did not converge, so no model could be developed. Table 27 shows there were 44 models that converged for the final analysis. This is an improvement on the Year 1 and Year 2 analysis, for which only 20 and 35 models converged. Thus, as additional years of data have become available, more models are being obtained in the cross-sectional analysis. Table 27 shows that the crash frequencies for the treatment sites after resurfacing were generally lower than for the comparison sites, indicating that the safety edge treatment was effective. However, statistically significant results for the safety edge effect (treatment vs. comparison sites) were obtained for 19 of the 44 models shown in the table. In 15 of these cases, the safety performance of the treatment sites was better than the comparison sites, indicating that the safety edge was effective. However, in four cases (three of which were on two-lane highways with unpaved shoulders in Georgia), the safety performance of the comparison sites was better than the treatment sites.

In summary, the cross-sectional analysis results are similar to the results of the EB analysis. These results suggest that the safety edge treatment is effective in reducing crashes, for sites with paved shoulders, and for sites in Indiana with unpaved shoulders. However, results for sites in Georgia with unpaved shoulders did not show that the safety edge was effective in reducing crashes.

The potential biases and limitations of this analysis are:

- there were some observed differences between treatment and comparison sites for the period before resurfacing (see discussion in Sections 3.1 and 4.3.1) which could confound the analysis results

Table 27. Cross-Sectional Analysis of Safety Edge Treatment Effect for the Period After Resurfacing

State	Roadway type	Shoulder type	Crash type and severity level[a]	Number of site-years	Intercept	AADT effect				Treatment effect				Dispersion parameter	R^2_{LR}%	Safety edge effect[b] (%)
						Coefficient	Standard error	p-Value	Statistically significant?[b]	Coefficient	Standard error	p-Value	Statistically significant?[b]			
GA	Multilane	Paved	TOT	51	-13.212	1.542	0.309	0.000	Y	-0.655	0.305	0.032	Y	0.282	48.4	48.1
			FI	51	-12.940	1.360	0.332	0.000	Y	-0.293	0.257	0.254	N	0.027	30.4	25.4
			PDO	51	-14.627	1.656	0.372	0.000	Y	-0.703	0.345	0.042	Y	0.404	44.0	50.5
			rorTOT	51	-19.840	2.114	0.329	0.000	Y	-0.946	0.201	0.000	Y	0.010	66.5	61.2
			rorFI	51	-15.748	1.562	0.391	0.000	Y	-0.410	0.244	0.092	Y	0.010	20.3	33.6
			rorPDO	51	-23.547	2.462	0.308	0.000	Y	-1.280	0.240	0.000	Y	0.010	61.8	72.2
			doTOT	51	-19.432	2.029	0.446	0.000	Y	-0.882	0.219	0.000	Y	0.010	48.8	58.6
			doFI	51	-18.509	1.841	0.380	0.000	Y	-0.610	0.121	0.000	Y	0.010	23.6	45.7
			doPDO	51	-20.271	2.061	0.552	0.000	Y	-1.130	0.354	0.001	Y	0.010	34.5	67.7
	Two-lane	Paved	TOT	132	-8.695	1.104	0.121	0.000	Y	0.111	0.183	0.545	N	0.178	51.0	-11.7
			FI	132	-7.501	0.880	0.182	0.000	Y	-0.197	0.264	0.457	N	0.273	27.4	17.8
			PDO	132	-11.162	1.306	0.125	0.000	Y	0.414	0.193	0.032	Y	0.136	49.6	-51.2
			rorTOT	132	-7.654	0.902	0.161	0.000	Y	-0.120	0.260	0.645	N	0.279	30.3	11.3
			rorFI	132	-5.201	0.546	0.197	0.006	Y	-0.497	0.355	0.161	N	0.453	11.5	39.2
			rorPDO	132	-12.208	1.322	0.216	0.000	Y	0.342	0.328	0.298	N	0.283	29.3	-40.8
			doTOT	132	-8.244	0.927	0.163	0.000	Y	-0.153	0.301	0.611	N	0.287	25.9	14.2
			doFI	132	-5.844	0.582	0.193	0.003	Y	-0.368	0.383	0.337	N	0.589	8.7	30.8
			doPDO	132	-14.467	1.518	0.276	0.000	Y	0.328	0.415	0.428	N	0.209	24.9	-38.9
		Unpaved	TOT	159	-10.116	1.253	0.173	0.000	Y	0.581	0.225	0.010	Y	0.555	37.0	-78.7
			FI	159	-8.599	0.959	0.182	0.000	Y	0.415	0.226	0.066	Y	0.267	24.3	-51.5
			PDO	159	-12.683	1.498	0.199	0.000	Y	0.594	0.274	0.030	Y	0.683	34.0	-81.1
			rorTOT	159	-7.229	0.799	0.169	0.000	Y	0.341	0.222	0.125	N	0.270	17.9	-40.6
			rorFI	159	-8.063	0.834	0.193	0.000	Y	0.275	0.265	0.301	N	0.217	14.4	-31.6
			rorPDO	159	-8.374	0.840	0.177	0.000	Y	0.365	0.255	0.152	N	0.262	12.0	-44.0
			doTOT	159	-7.422	0.773	0.196	0.000	Y	0.379	0.262	0.149	N	0.301	14.2	-46.0
			doFI	159	-8.725	0.882	0.202	0.000	Y	0.297	0.257	0.248	N	0.128	14.0	-34.6
			doPDO	159	-8.048	0.728	0.243	0.003	Y	0.411	0.344	0.231	N	0.402	6.8	-50.9

[a] Crash types and severity levels:
TOT = total crashes (all severity levels combined)
FI = fatal–and–injury crashes
PDO = property–damage-only crashes
ror = run-off-road crashes
do = drop-off-related crashes
[b] Percent difference between treatment and comparison sites.
[c] At the 0.10 level.

Table 27. Cross-Sectional Analysis of Safety Edge Treatment Effect for the Period After Resurfacing (Continued)

State	Roadway type	Shoulder type	Crash type and severity level[a]	Number of site-years	Intercept	AADT effect				Treatment effect				Dispersion parameter	R^2_{LR}%	Safety edge effect[b] (%)
						Coefficient	Standard error	p-Value	Statistically significant?[b]	Coefficient	Standard error	p-Value	Statistically significant?[b]			
IN	Two-lane	Paved	TOT	63												
			FI	63	-1.982	0.117	0.647	0.856	N	-0.819	0.582	0.159	N	0.853	4.2	55.9
			PDO	63												
			rorTOT	63												
			rorFI	63												
			rorPDO	63												
			doTOT	63												
			doFI	63	-13.163	1.184	3.132	0.705	N	-1.599	0.729	0.028	Y	0.010	3.0	79.8
			doPDO	63												
		Unpaved	TOT	102	-4.887	0.543	0.256	0.034	Y	-0.069	0.211	0.742	N	0.653	7.4	6.7
			FI	102	-5.650	0.493	0.313	0.115	N	-1.215	0.492	0.013	Y	0.757	9.4	70.3
			PDO	102	-5.657	0.594	0.269	0.027	Y	0.206	0.231	0.373	N	0.697	6.1	-22.9
			rorTOT	102	-3.429	0.273	0.396	0.491	N	-0.864	0.394	0.028	Y	0.527	8.7	57.9
			rorFI	102	-3.926	0.219	0.399	0.583	N	-1.689	0.610	0.006	Y	0.247	10.2	81.5
			rorPDO	102	-4.619	0.358	0.499	0.473	N	-0.486	0.417	0.244	N	0.972	3.4	38.5
			doTOT	102	-5.486	0.488	0.363	0.178	N	-1.206	0.389	0.002	Y	0.320	11.1	70.1
			doFI	102	-9.490	0.869	0.355	0.014	Y	-1.970	1.029	0.056	Y	0.010	9.3	86.0
			doPDO	102	-4.672	0.327	0.525	0.534	N	-0.990	0.407	0.015	Y	0.718	5.4	62.8
NY	Two-lane	Paved	TOT	18	-3.595	0.510	0.186	0.006	Y	-0.278	0.273	0.307	N	0.117	28.4	24.3
			FI	18	-9.373	1.040	0.134	0.000	Y	0.092	0.144	0.525	N	0.010	57.9	-9.6
			PDO	18	-2.241	0.311	0.281	0.268	N	-0.440	0.405	0.277	N	0.214	16.9	35.6
			rorTOT	18	-4.255	0.480	0.174	0.006	Y	-0.128	0.271	0.638	N	0.010	28.5	12.0
			rorFI	18	-9.553	1.035	0.101	0.000	Y	0.004	0.135	0.976	N	0.010	48.7	-0.4
			rorPDO	18												
			doTOT	18												
			doFI	18												
			doPDO	18												

[a] Crash types and severity levels:
TOT = total crashes (all severity levels combined)
FI = fatal–and–injury crashes
PDO = property–damage-only crashes
ror = run-off-road crashes
do = drop-off-related crashes

[b] Percent difference between treatment and comparison sites.

[c] At the 0.10 level.

- the sites with unpaved shoulders, where the safety edge treatment would be expected to be most effective, also had the lowest crash frequencies which increased the variability in the data and made the statistical test less powerful.
- The cross-sectional approach does not explicitly compensate for regression to the mean

4.3.4 Analysis of Shifts in the Crash Severity Distribution

An analysis was conducted to assess whether safety edge treatment affected the proportion of severe crashes for specific crash types. This analysis compared fatal-and-injury crashes as a proportion of total crashes in the periods before and after resurfacing for each state/roadway type/ shoulder type combination. Results of this analysis are presented in Table 28. The fatal-and-injury crash proportions were evaluated for run-off-road crashes, drop-off-related crashes, and all crash types combined. These comparisons were made by estimating the mean difference in proportions and its confidence interval across all sites at a significance level of 10 percent.

These evaluations were performed with the Wilcoxon signed rank test, a nonparametric test that does not require that the differences being considered follow a normal distribution. The Wilcoxon signed rank test was programmed in SAS using the algorithm developed for the FHWA *SafetyAnalyst* software (*9*). The primary measures of interest presented in Table 28 for differences in proportion of fatal-and-injury crashes are:

- Average proportion of fatal-and-injury crashes before resurfacing
- Average proportion of fatal-and-injury crashes after resurfacing
- Simple average difference in proportions (after-before)
- Number of sites included in the analysis
- Estimated median before-after effect
- Lower confidence limit of median before-after effect
- Upper confidence limit of median before-after effect
- Summary of statistical significance

The estimated average treatment effect is the difference between the proportions for the periods before and after resurfacing, based only on those sites where the difference is non-zero. Since, the Wilcoxon signed rank test uses only those sites with an observed non-zero change in the proportion of fatal-and-injury crashes, it estimates the median rather than the mean. Consequently, the test results are less influenced by extreme changes in proportions. Cases in which the test of proportions could not be conducted are left blank in the table.

A negative estimated median difference indicates that the proportion of fatal-and-injury crashes decreased. If the number of sites was less than four, no test was conducted.

The proportion of severe crashes after resurfacing was lower than the proportion of severe crashes before resurfacing in 31 out of 58 cases shown in Table 28; 13 of the 31 positive results were for sites resurfaced with the safety edge treatment and 18 were for sites resurfaced without the safety edge treatment. Only 4 of the 58 comparisons of severity proportions were statistically significant; all 4 of these cases were comparison sites. Overall, it appears that the proportion of severe crashes was reduced from before to after resurfacing, but only a few of the results were statistically significant and there is no apparent difference in the shift in severity distributions between resurfacing with and without the safety edge treatment.

Table 28. Comparison of Proportions of Fatal and Injury Crashes Before and After Resurfacing

Crash type[a]	State	Roadway type	Shoulder Type	Site type[b]	Average before proportion	Average after proportion	Estimated average difference	Number of Sites	Estimated mean difference	Lower 90% confidence limit	Upper 90% confidence limit	Significant at the 0.10 level?
TOT	GA	Multilane	Paved	T	0.362	0.397	0.035	10	0.088	–0.115	0.208	No
				C	0.353	0.370	0.017	6	–0.024	–0.272	0.334	No
		Two-lane	Paved	T	0.276	0.246	–0.030	15	–0.030	–0.132	0.054	No
				C	0.414	0.444	0.031	13	0.042	–0.167	0.296	No
			Unpaved	T	0.209	0.476	0.267	20	0.238	0.088	0.480	Yes
				C	0.384	0.317	–0.067	24	–0.025	–0.151	0.085	No
			All	T	0.245	0.354	0.109	35	0.099	0.006	0.216	Yes
				C	0.395	0.366	–0.030	37	–0.009	–0.122	0.095	No
	IN	Two-lane	Paved	T	0.116	0.154	0.038	8	0.007	–0.172	0.286	No
				C	0.222	0.165	–0.058	6	–0.034	–0.242	0.069	No
			Unpaved	T	0.111	0.088	–0.023	7	–0.166	–0.276	0.218	No
				C	0.233	0.271	0.038	14	0.044	–0.042	0.165	No
			All	T	0.113	0.119	0.005	15	–0.047	–0.188	0.190	No
				C	0.230	0.241	0.011	20	0.017	–0.072	0.106	No
	NY	Two-lane	Paved	T	0.507	0.334	–0.172	3	–0.181			No Test
				C	0.407	0.219	–0.188	3	–0.188			No Test
	All	Two-lane	Paved	T	0.239	0.221	–0.018	26	–0.044	–0.116	0.045	No
				C	0.367	0.354	–0.013	22	–0.032	–0.150	0.108	No
			Unpaved	T	0.168	0.313	0.145	27	0.156	0.022	0.350	Yes
				C	0.329	0.300	–0.028	38	0.008	–0.083	0.079	No
			All	T	0.205	0.265	0.059	53				No
				C	0.343	0.320	–0.023	60				No
ROR	GA	Multilane	Paved	T	0.340	0.459	0.119	9	0.168	–0.083	0.357	No
				C	0.378	0.154	–0.224	6	–0.250	–0.400	–0.143	Yes
		Two-lane	Paved	T	0.331	0.234	–0.097	17	–0.148	–0.297	0.035	No
				C	0.386	0.361	–0.025	11	–0.035	–0.467	0.321	No
			Unpaved	T	0.309	0.491	0.182	14	0.250	0.021	0.542	Yes
				C	0.339	0.366	0.026	19	0.065	–0.126	0.250	No
			All	T	0.321	0.355	0.034	31	0.035	–0.125	0.200	No
				C	0.357	0.364	0.007	30	0.024	–0.142	0.214	No
	IN	Two-lane	Paved	T	0.063	0.139	0.077	5	0.179	–0.171	0.750	No
				C	0.486	0.193	–0.293	6	–0.317	–0.708	0.000	No
			Unpaved	T	0.207	0.096	–0.111	8	–0.333	–0.667	0.313	No
				C	0.367	0.413	0.046	11	0.042	–0.294	0.387	No
			All	T	0.140	0.116	–0.024	13	–0.108	–0.333	0.333	No
				C	0.400	0.351	–0.049	17	–0.113	–0.317	0.173	No
	NY	Two-lane	Paved	T	0.685	0.519	–0.166	3	–0.156			No Test
				C	0.628	0.635	0.007	3	–0.023			No Test
	All	Two-lane	Paved	T	0.267	0.223	–0.044	25	–0.097	–0.229	0.065	No
				C	0.435	0.349	–0.086	20	–0.133	–0.367	0.100	No
			Unpaved	T	0.266	0.325	0.059	22	0.089	–0.110	0.333	No

Table 28. Comparison of Proportions of Fatal and Injury Crashes Before and After Resurfacing (Continued)

Crash type[a]	State	Roadway type	Shoulder Type	Site type[b]	Average before proportion	Average after proportion	Estimated average difference	Number of Sites	Estimated mean difference	Lower 90% confidence limit	Upper 90% confidence limit	Significant at the 0.10 level?
				C	0.350	0.383	0.034	30	0.061	–0.097	0.217	No
			All	T	0.267	0.271	0.005	47	–0.011	–0.134	0.122	No
				C	0.381	0.370	–0.011	50	–0.008	–0.142	0.117	No
DO	GA	Multilane	Paved	T	0.410	0.526	0.116	9	0.167	–0.083	0.333	No
				C	0.401	0.186	–0.216	6	–0.250	–0.458	–0.057	Yes
		Two-lane	Paved	T	0.416	0.313	–0.103	14	–0.200	–0.455	0.089	No
				C	0.399	0.308	–0.091	12	–0.152	–0.500	0.250	No
			Unpaved	T	0.305	0.562	0.257	17	0.375	0.104	0.563	Yes
				C	0.285	0.355	0.070	18	0.151	–0.089	0.333	No
			All	T	0.364	0.430	0.066	31	0.100	–0.075	0.292	No
				C	0.328	0.337	0.009	30	0.000	–0.199	0.250	No
	IN	Two-lane	Paved	T	0.000	0.071	0.071	1	1.000			No Test
				C	0.238	0.097	–0.141	2	–0.492			No Test
			Unpaved	T	0.141	0.063	–0.078	4	–0.438	–1.000	1.000	No
				C	0.435	0.289	–0.146	11	–0.338	–0.583	0.125	No
			All	T	0.075	0.067	–0.008	5	0.000	–1.000	1.000	No
				C	0.380	0.236	–0.144	13	–0.375	–0.554	0.000	Yes
	NY	Two-lane	Paved	T	0.667	0.000	–0.667	2	–1.000			No Test
				C	0.667	0.167	–0.500	2	–0.750			No Test
	All	Two-lane	Paved	T	0.295	0.210	–0.085	17	–0.211	–0.472	0.078	No
				C	0.388	0.243	–0.145	16	–0.300	–0.550	0.000	Yes
			Unpaved	T	0.236	0.352	0.116	21	0.250	0.000	0.508	No
				C	0.340	0.331	–0.009	29	–0.003	–0.217	0.183	No
			All	T	0.267	0.277	0.010	38	0.000	–0.181	0.250	No
				C	0.358	0.298	–0.060	45	–0.113	–0.289	0.028	No

[a]Crash types:
TOT = Total Crashes
ROR = Run-off-road crashes
DO = Drop-off-related crashes
[b] Site types:
T = Treatment sites resurfaced with safety edge
C = Comparison sites resurfaced without safety edge

Section 5.
Estimated Cost of the Safety Edge Treatment

This section presents the analysis results for the cost of the safety edge treatment. Section 5.1 discusses an analysis of contract costs of both the treatment and comparison resurfacing contracts, and Section 5.2 presents another method for determining the cost of the safety edge.

5.1 Comparison of Overall Costs of Resurfacing Projects

Since the safety edge treatment adds a wedge of asphalt to each edge of the roadway, it would be expected to add an additional cost to a resurfacing project. Costs of resurfacing for both treatment and comparison sites (i.e., sites resurfaced both with and without the safety edge), were obtained from each of the participating states after the resurfacing project was completed and project accounts were finalized. The cost items obtained for each project included the engineer's estimate of the cost, the contract cost or price actually bid for the project by the winning bidder, and the cost per ton of the hot-mix asphalt concrete (HMA) used to resurface the roadway and to form the safety edge.

The Georgia data set included 28 resurfacing projects (15 treatment and 13 comparison sites) and 557 km (345 mi) of roadway. A summary of the project costs for Georgia is shown in Table 29. Costs per mile of safety edge resurfacing vs. non-safety-edge resurfacing were found to be $110,000 vs. $140,000.

Table 29. Summary of Georgia Resurfacing Project Costs (2005)

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison sites
Engineer's estimate ($ million/mi)	$2.650	$1.353	$3.222	$1.272
Contract cost ($ million/mi)	$1.306	$1.353	$1.183	$1.268
HMA surfacing cost ($/ton)	$45.730	$43.050	$49.210	$42.970
HMA surfacing cost ($ million/mi)	----------	----------	$0.110	$0.140

The Indiana data set includes 16 resurfacing projects (8 treatment and 8 comparison sites) and 265 km (165 mi) of roadway. A summary of the project costs for Indiana is shown in Table 30. Costs per mile of safety edge resurfacing vs. non-safety edge resurfacing were found to be $140,000 vs. $150,000.

Table 30. Summary of Indiana Resurfacing Project Costs (2005)

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison sites
Engineer's estimate ($ million/mi)	$1.878	$1.766	$1.748	$1.691
Contract cost ($ million/mi)	$1.505	$1.419	$1.407	$1.388
HMA surfacing cost ($/ton)	$38.200	$35.510	$38.600	$35.650
HMA surfacing cost ($ million/mi)	----------	----------	$0.140	$0.150

The New York data set included 6 resurfacing projects (3 treatment and 3 comparison sites) and 40 km (25 mi) of roadway. A summary of the costs for New York projects is shown in Table 31. Costs per mile of safety edge resurfacing vs. non-safety-edge treatment were found to be $30,000 vs. $40,000. Costs for New York projects are substantially less than Indiana and Georgia. The HMA costs were generally higher in Indiana and Georgia than in New York, but it is also possible that the New York projects may differ in scope from those in Indiana and Georgia.

Table 31. Summary of New York Resurfacing Project Costs (2005)

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison sites
Engineer's estimate ($ million/mi)	$0.368	$0.881	$0.354	$0.737
Contract cost ($ million/mi)	$0.106	$0.145	$0.108	$0.143
HMA surfacing cost ($/ton)	$40.290	$49.180	$40.670	$51.710
HMA surfacing cost ($ million/mi)	----------	----------	$0.030	$0.040

The cost analyses for resurfacing with the safety edge treatments as compared to resurfacing projects on similar roads without the safety edge treatment were reviewed collectively and individually. A summary of the resurfacing costs for all three states combined is shown in Table 32. Collectively, the cost of resurfacing with the safety edge treatment was found to be slightly less than without the safety edge treatment. Earlier analysis of the yield of coverage on safety edge and non-safety edge sites in Georgia found only a very small difference in the amount of area covered per ton of asphalt.

Some advocates of the safety edge treatment maintain that incorporating this treatment in resurfacing projects has little, if any, added cost because the asphalt used in

Table 32. Summary of Combined Georgia, Indiana, and New York Resurfacing Project Costs (2005)

Cost item	Weighted average cost		Nonweighted average cost	
	Safety edge sites	Comparison sites	Safety edge sites	Comparison sites
Engineer's estimate ($ million/mi)	$1.632	$1.333	$1.775	$1.233
Contract cost ($ million/mi)	$0.973	$0.973	$0.899	$0.933
HMA surfacing cost ($/ton)	$41.407	$42.578	$42.830	$43.445
HMA surfacing cost ($ million/mi)	----------	----------	$0.096	$0.110

resurfacing is merely reformed to create the safety edge treatment. The results summarized in Table 32 can be interpreted as consistent with this hypothesis. However, construction practices vary between contractors and highway agencies and, while the amount of asphalt used for the safety edge treatment may be very small, it appears unrealistic to assume that there is no additional cost to implement this treatment. The next section presents an alternative approach to estimating the additional cost per mile of providing the safety edge treatment.

5.2 Cost of Safety Edge Treatment Based on Amount of Asphalt Used

An alternative method to determine the cost of the safety edge treatment is to compute the amount of asphalt used to provide the safety edge treatment and multiply this quantity by a typical bid cost per ton for HMA for that specific project.

Figure 5 shows a typical triangular cross section for the safety edge treatment. The safety edge treatment is shown with a cross slope of 30°, which is consistent with current practice. The cost per mile for the safety edge treatment on both sides of the road, based on the cross section shown in Figure 5, can be estimated as:

$$CC_{SE} = \frac{(A)(L)(D)(C)}{(2000)} \qquad \textbf{(5)}$$

where:

CC_{SE} = cost for application of the safety edge treatment ($ per mi)

A = area of the safety edge treatment cross section (ft^2) [= 0.5 (h/12) $\frac{h/\tan 30°}{12}$]

h = height of safety edge treatment (inches)
L = length of safety edge treatment (ft)
D = HMA density ($1b/ft^3$)
C = HMA cost ($/ton)

The height of the safety edge treatment (h) is estimated to range from 38 to 76 mm (1.5 to 3.0 inches), based on the assumption that a 38-mm (1.5-inch) overlay will be placed and that the shoulder will be leveled between 0 to 38 mm (0 to 1.5 inches) below the elevation of the pavement existing before resurfacing.

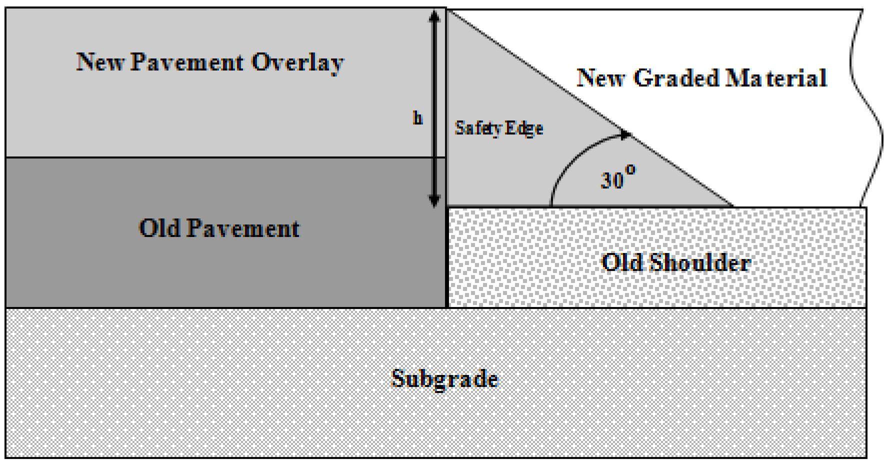

Figure 5. Typical Cross Section for the Safety Edge Treatment on One Side of the Road Used for Cost Estimation

The length of the safety edge treatment (L) for a 1.6-km (1.0-mi) road section would be 3.2 km (2.0 mi) or 3,200 m (10,560 ft) for both sides of the road combined.

The density of the HMA for the safety edge treatment is estimated to be 1,602 kg/m^3 (100 $1b/ft^3$). This is less than the maximum density of compacted asphalt, because the safety edge treatment is not compacted as an overlay course would be.

The cost of HMA has increased since the 2005 costs shown in Tables 29 through 32. HMA costs vary substantially between regions of the U.S. Based on discussions with several highway agencies, a representative current price for HMA is $82.5/metric ton ($75/ton).

Applying Equation (5) to the values discussed above, the cost for a safety edge treatment 38-mm (1.5-inch) high would be $333 per km ($536 per mi). The cost for a safety edge treatment 76-mm (3.0-inch) high would be $1,333 per km ($2,145 per mi). Thus, a reasonable range of costs for the safety edge treatment is $333 to 1,333 per km ($536 to 2,145 per mi).

Section 6. Benefit-Cost Analysis

This section presents the results of a benefit-cost analysis of the safety edge treatment based on the results presented in this report. Section 6.1 presents the overall approach to determining benefit-cost estimates, Section 6.2 documents the components of the analysis, and Section 6.3 discusses the results of the benefit-cost analysis.

6.1 Benefit-Cost Analysis Approach

The benefit-cost ratio for the safety edge treatment has been determined as:

$$B/C = \frac{(N_{FI} E_{SE} C_{FI} + N_{PDO} E_{SE} C_{PDO})(P/A, i\%, n)}{CC_{SE}} \qquad \textbf{(6)}$$

where:

B/C	=	benefit-cost ratio
N_{FI}	=	number of fatal-and-injury crashes per mi per year before application of the safety edge treatment
N_{PDO}	=	number of property-damage-only crashes per mi per year before application of the safety edge treatment
E_{SE}	=	effectiveness (percentage reduction in crashes) for application of the safety edge treatment
C_{FI}	=	cost savings per crash for fatal-and-injury crashes reduced
C_{PDO}	=	cost savings per crash for property-damage-only crashes reduced
(P/A, *i*, n)	=	uniform series present worth factor
i	=	minimum attractive rate of return (discount rate) (expressed as a proportion, i.e., $i = 0.04$ for a discount rate of 4 percent)
n	=	service life of safety edge treatment (years)
CC_{SE}	=	cost for application of the safety edge treatment ($ per mi)

6.2 Components of the Benefit-Cost Analysis

The following discussion documents the components of the benefit-cost computation including crash frequencies, treatment effectiveness, crash costs, service life, minimum attractive rate of return, uniform series present worth factor, and treatment cost.

6.2.1 Crash Frequencies

Crash frequencies per mi per year have been estimated for the benefit-cost analysis using the SPFs presented in Section 4.2 of this report. Only two-lane highway sites were considered because no treatment effectiveness measure was found for multilane highway sites. Both Georgia and Indiana SPFs were used, because each state has separate SPFs and because using the individual state SPFs constitutes a sensitivity analysis of the results. The SPFs used in the benefit-cost analysis are as follows:

State	Roadway type	Shoulder type	Crash type and security level	Table
Georgia	Two-lane highway	Paved	All crashes	10
Georgia	Two-lane highway	Paved	E&I crashes	10
Georgia	Two-lane highway	Paved	PDO crashes	10
Indiana	Two-lane highway	Paved	All crashes	11
Indiana	Two-lane highway	Paved	F&I crashes	11
Indiana	Two-lane highway	Paved	PDO crashes	11
Georgia	Two-lane highway	Unpaved	All crashes	10
Georgia	Two-lane highway	Unpaved	F&I crashes	10
Georgia	Two-lane highway	Unpaved	PDO crashes	10
Indiana	Two-lane highway	Unpaved	All crashes	11
Indiana	Two-lane highway	Unpaved	F&I crashes	11
Indiana	Two-lane highway	Unpaved	PDO crashes	11

The computation of crash frequencies was performed as illustrated in the following example of Georgia two-lane highways with paved shoulders. This example illustrates the computation of crash frequencies per mi per year for highways with a traffic volume of 1,000 veh/day:

SPF for total crashes from Table 10:

$$N_{TOT} = \exp(-8.921 + 1.108 \ln(1{,}000)) = 0.282 \text{ crashes per mi per year}$$

SPF for F&I crashes from Table 10:

$$N_{FI} = \exp(-7.818 + 0.853 \ln(1{,}000)) = 0.146 \text{ crashes per mi per year}$$

SPF for PDO crashes from Table 10:

$$N_{PDO} = \exp(-11.414 + 1.349 \ln(1{,}000)) = 0.123 \text{ crashes per mi per year}$$

Since the sum of N_{FI} (0.146) and N_{PDO} (0.123) is less than N_{TOT} (0.282), the values of N_{FI} and N_{PDO} are adjusted so that this sum is equal to N_{TOT}, as follows:

$$N_{FI}\text{ (adjusted)} = 0.282\left(\frac{0.146}{0.146+0.123}\right) = 0.153\text{ crashes per mi per year}$$

$$N_{PDO}\text{ (adjusted)} = 0.282\left(\frac{0.123}{0.146+0.123}\right) = 0.129\text{ crashes per mi per year}$$

6.2.2 Treatment Effectiveness

Based on the results of the EB evaluation presented in 4.3.2, the crash reduction effectiveness of the safety edge treatment is estimated as 5.7 percent. Continuing the computational example started above for Georgia two-lane highways with paved shoulders with a traffic volume of 1,000 veh/day, the crash reduction from the safety edge treatment would be estimated as:

For F&I crashes:

0.153 (0.057) = 0.008721 crashes reduced per mi per year

For PDO crashes:

0.129 (0.057) = 0.007353 crashes reduced per mi per year

6.2.3 Crash Costs

The estimated crash costs used in this analysis are based on those currently used in *SafetyAnalyst* (*9*):

Fatal crash	$5,800,000
A injury crash	402,000
B injury crash	80,000
C injury crash	42,000
Property-damage-only crash	4,000

The costs are based on the latest published FHWA values. (*12*) The weighted average cost of a fatal-and-injury crash (assuming 1 percent fatal crashes, 9 percent A injury crashes, 50 percent B injury crashes, and 40 percent C injury crashes) is $150,980 per crash. Based on these crash costs, the estimated annual crash reduction benefits for the example presented above are:

0.008721 (150,980) + (.007353) (4,000) = $1,346 per mi

6.2.4 Service Life

The service life of the safety edge treatment is estimated to be 7 years, the same as the service life of a typical pavement resurfacing project.

6.2.5 Minimum Attractive Rate of Return

The minimum attractive rate of return for this analysis is estimated to be 4 percent. This value is currently used in *SafetyAnalyst* (*9*) and is representative of the real, long-term cost of capital (i.e., not including inflation).

6.2.6 Uniform Series Present Worth Factor

The uniform series present worth factor is applied to convert the annual crash reduction benefits to a present value. This factor is determined as:

$$(\text{P/A}, i, \text{n}) = \frac{(1+i)^n - 1}{i(1+i)^n} \quad \mathbf{(7)}$$

The uniform series present worth factor for a minimum attractive rate of return of 4 percent and a service life of 7 years is determined as:

$$(\text{P/A}, 4\%, 7) = \frac{(1+0.04)^7 - 1}{0.04(1+0.04)^7} = 6.002$$

6.2.7 Treatment Cost

The cost of the safety edge treatment is estimated as falling in the range from $536 to $2,145 per mi for both sides of the road combined, as explained in Section 5.2.

6.2.8 Benefit Cost Ratio

The value of the benefit-cost ratio is computed using Equation (6). For the computational example presented above, the maximum benefit-cost ratio (estimated for the minimum treatment cost of $536 per mi) is determined as:

$$\text{B/C} = \frac{(1{,}346)(6.002)}{536} = 15.07$$

The minimum benefit-cost ratio for the same case (estimated for the maximum treatment cost of $2,145 per mi) is determined as:

$$B/C = \frac{(1{,}346)(6.002)}{2{,}145} = 3.77$$

The result indicates that, in this example, the safety edge treatment provides at least 3 dollars in benefits for each dollar spent on the treatment, and possibly as much as 15 dollars in benefits for each dollar spent on the treatment depending on the thickness of the safety edge treatment provided. This computation example addressed sites with a traffic volume of 1,000 veh/day. Larger benefit-cost ratios would be expected for sites with higher traffic volumes.

6.3 Benefit-Cost Analysis Results

The results of the benefit-cost analysis are summarized in Tables 33 through 36 for application of the safety edge treatment to the following types of roadways:

State/Roadway Type	Table
Georgia two-lane highways with paved shoulders	33
Indiana two-lane highways with paved shoulders	34
Georgia two-lane highways with unpaved shoulders	35
Indiana two-lane highways with unpaved shoulders	36

For each state and roadway type, benefit-cost analyses have been performed for traffic volumes ranging from 1,000 to 20,000 veh/day. The overall results of the benefit-cost analysis are illustrated in Figures 6 and 7.

For two-lane highways with paved shoulders, application of the safety edge treatment has minimum benefit-cost ratios ranging from 3.8 to 43.6 for Georgia conditions and 3.9 to 30.6 for Indiana conditions. For two-lane highways with unpaved shoulders, the minimum benefit-cost ratios for the safety edge treatment range from 3.7 to 62.8 for Georgia conditions and 2.8 to 12.8 for Indiana conditions. In all these cases, the maximum benefit-cost ratios are four times the minimum benefit-cost ratios.

These results suggest that the safety edge treatment is highly cost-effective under a broad range of conditions. Even though there is uncertainty in the treatment effectiveness estimate, the safety edge treatment is likely to be a good safety investment in most situations, and this is especially so for roadways with higher volume levels where higher crash frequencies are expected.

Table 33. Summary of Benefit-Cost Analysis for Application of Safety Edge Treatment on Georgia Two-Lane Roadways with Paved Shoulders

AADT (veh/day)	1,000	5,000	10,000	15,000	20,000
CRASH FREQUENCIES					
Total crashes per mi per year	0.282	1.675	3.611	5.659	7.784
F&I crashes per mi per year	0.146	0.575	1.039	1.469	1.877
PDO crashes per mi per year	0.123	1.079	2.748	4.748	6.999
F&I crashes per mi per year (adjusted)	0.153	0.583	0.991	1.337	1.646
PDO crashes per mi per year (adjusted)	0.129	1.093	2.620	4.322	6.138
SAFETY BENEFITS -- Number of crashes reduced					
F&I crashes reduced per mi per year	0.009	0.033	0.056	0.076	0.094
PDO crashes reduced per mi per year	0.007	0.062	0.149	0.246	0.350
SAFETY BENEFITS – Dollars					
F&I crash reduction benefits per year ($)	1,314	5,015	8,528	11,505	14,165
PDO crash reduction benefits per year ($)	29	249	597	986	1,399
Total crash reduction benefits per year ($)	1,344	5,264	9,126	12,491	15,565
Present value of total benefits per year ($)	8,065	31,597	54,773	74,972	93,421
TREATMENT COST					
Minimum cost of safety edge treatment ($ per mi)	536	536	536	536	536
Maximum cost of safety edge treatment ($ per mi)	2,145	2,145	2,145	2,145	2,145
BENEFIT-COST RATIO					
Minimum benefit-cost ratio	3.8	14.7	25.5	35.0	43.6
Maximum benefit-cost ratio	15.0	59.0	102.2	139.9	174.3

Table 34. Summary of Benefit-Cost Analysis for Application of Safety Edge Treatment on Indiana Two-Lane Roadways with Paved Shoulders

AADT (veh/day)	1,000	5,000	10,000	15,000	20,000
CRASH FREQUENCIES					
Total crashes per mi per year	0.664	2.175	3.626	4.888	6.043
F&I crashes per mi per year	0.158	0.444	0.694	0.900	1.082
PDO crashes per mi per year	0.542	1.722	2.832	3.789	4.659
F&I crashes per mi per year (adjusted)	0.150	0.446	0.713	0.938	1.139
PDO crashes per mi per year (adjusted)	0.514	1.729	2.912	3.950	4.904
SAFETY BENEFITS -- Number of crashes reduced					
F&I crashes reduced per mi per year	0.009	0.025	0.041	0.053	0.065
PDO crashes reduced per mi per year	0.029	0.099	0.166	0.225	0.280
SAFETY BENEFITS – Dollars					
F&I crash reduction benefits ($)	1,291	3,841	6,138	8,072	9,804
PDO crash reduction benefits ($)	117	394	664	901	1,118
Total crash reduction benefits ($)	1,408	4,235	6,802	8,973	10,922
Present value of total benefits ($)	8,453	25,419	40,824	53,856	65,553
TREATMENT COST					
Minimum cost of safety edge treatment (per mi)	536	536	536	536	536
Maximum cost of safety edge treatment (per mi)	2,145	2,145	2,145	2,145	2,145
BENEFIT-COST RATIO					
Minimum benefit-cost ratio	3.9	11.9	19.0	25.1	30.6
Maximum benefit-cost ratio	15.8	47.4	76.2	100.5	122.3

Table 35. Summary of Benefit-Cost Analysis for Application of Safety Edge Treatment on Georgia Two-Lane Roadways with Unpaved Shoulders

AADT (veh/day)	1,000	5,000	10,000	15,000	20,000
CRASH FREQUENCIES					
Total crashes per mi per year	0.377	1.822	3.588	5.335	7.068
F&I crashes per mi per year	0.144	0.673	1.307	1.927	2.538
PDO crashes per mi per year	0.226	1.151	2.320	3.496	4.676
F&I crashes per mi per year (adjusted)	0.147	0.672	1.293	1.896	2.487
PDO crashes per mi per year (adjusted)	0.231	1.150	2.296	3.439	4.581
SAFETY BENEFITS -- Number of crashes reduced					
F&I crashes reduced per mi per year	0.008	0.038	0.074	0.108	0.142
PDO crashes reduced per mi per year	0.013	0.066	0.131	0.196	0.261
SAFETY BENEFITS – Dollars					
F&I crash reduction benefits ($)	1,263	5,782	11,126	16,314	21,403
PDO crash reduction benefits ($)	53	262	523	784	1,045
Total crash reduction benefits ($)	1,316	6,044	11,649	17,098	22,447
Present value of total benefits ($)	7,898	36,277	69,920	102,624	134,730
TREATMENT COST					
Minimum cost of safety edge treatment (per mi)	536	536	536	536	536
Maximum cost of safety edge treatment (per mi)	2,145	2,145	2,145	2,145	2,145
BENEFIT-COST RATIO					
Minimum benefit-cost ratio	3.7	16.9	32.5	47.8	62.8
Maximum benefit-cost ratio	14.7	67.7	130.4	191.5	251.4

Table 36. Summary of Benefit-Cost Analysis for Application of Safety Edge Treatment on Indiana Two-Lane Roadways with Unpaved Shoulders

AADT (veh/day)	1,000	5,000	10,000	15,000	20,000
CRASH FREQUENCIES					
Total crashes per mi per year	0.409	1.263	2.053	2.728	3.338
F&I crashes per mi per year	0.118	0.235	0.317	0.376	0.426
PDO crashes per mi per year	0.336	1.027	1.662	2.202	2.689
F&I crashes per mi per year (adjusted)	0.106	0.236	0.329	0.398	0.456
PDO crashes per mi per year (adjusted)	0.302	1.028	1.725	2.330	2.882
SAFETY BENEFITS -- Number of crashes reduced					
F&I crashes reduced per mi per year	0.006	0.013	0.019	0.023	0.026
PDO crashes reduced per mi per year	0.017	0.059	0.098	0.133	0.164
SAFETY BENEFITS – Dollars					
F&I crash reduction benefits ($)	916	2,027	2,827	3,428	3,926
PDO crash reduction benefits ($)	69	234	393	531	657
Total crash reduction benefits ($)	985	2,261	3,221	3,959	4,583
Present value of total benefits ($)	5,914	13,572	19,331	23,762	27,507
TREATMENT COST					
Minimum cost of safety edge treatment (per mi)	536	536	536	536	536
Maximum cost of safety edge treatment (per mi)	2,145	2,145	2,145	2,145	2,145
BENEFIT-COST RATIO					
Minimum benefit-cost ratio	2.8	6.3	9.0	11.1	12.8
Maximum benefit-cost ratio	11.0	25.3	36.1	44.3	51.3

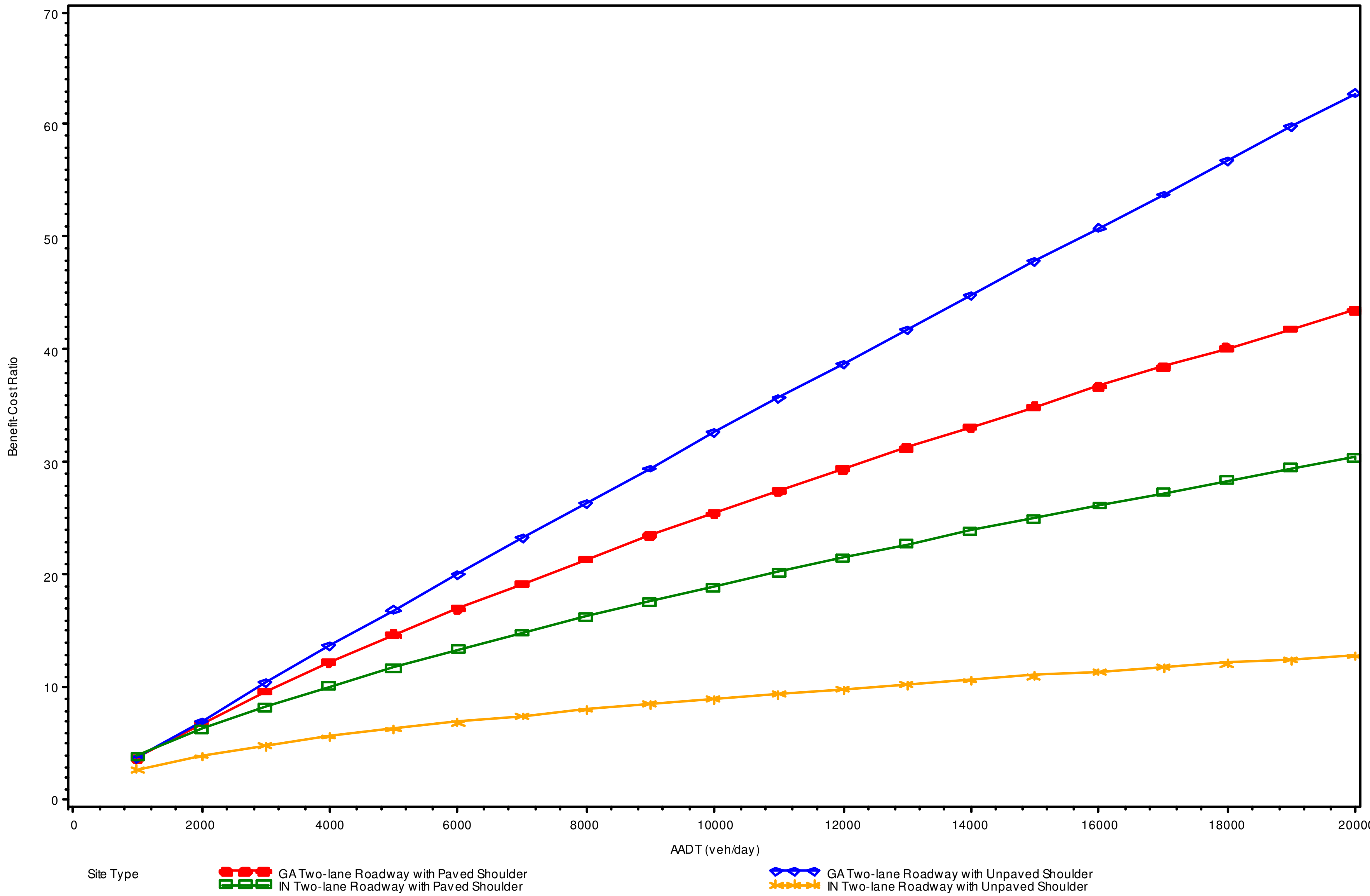

Figure 6. Minimum Benefit-cost Ratios for the Safety Edge Treatment as a Function of AADT

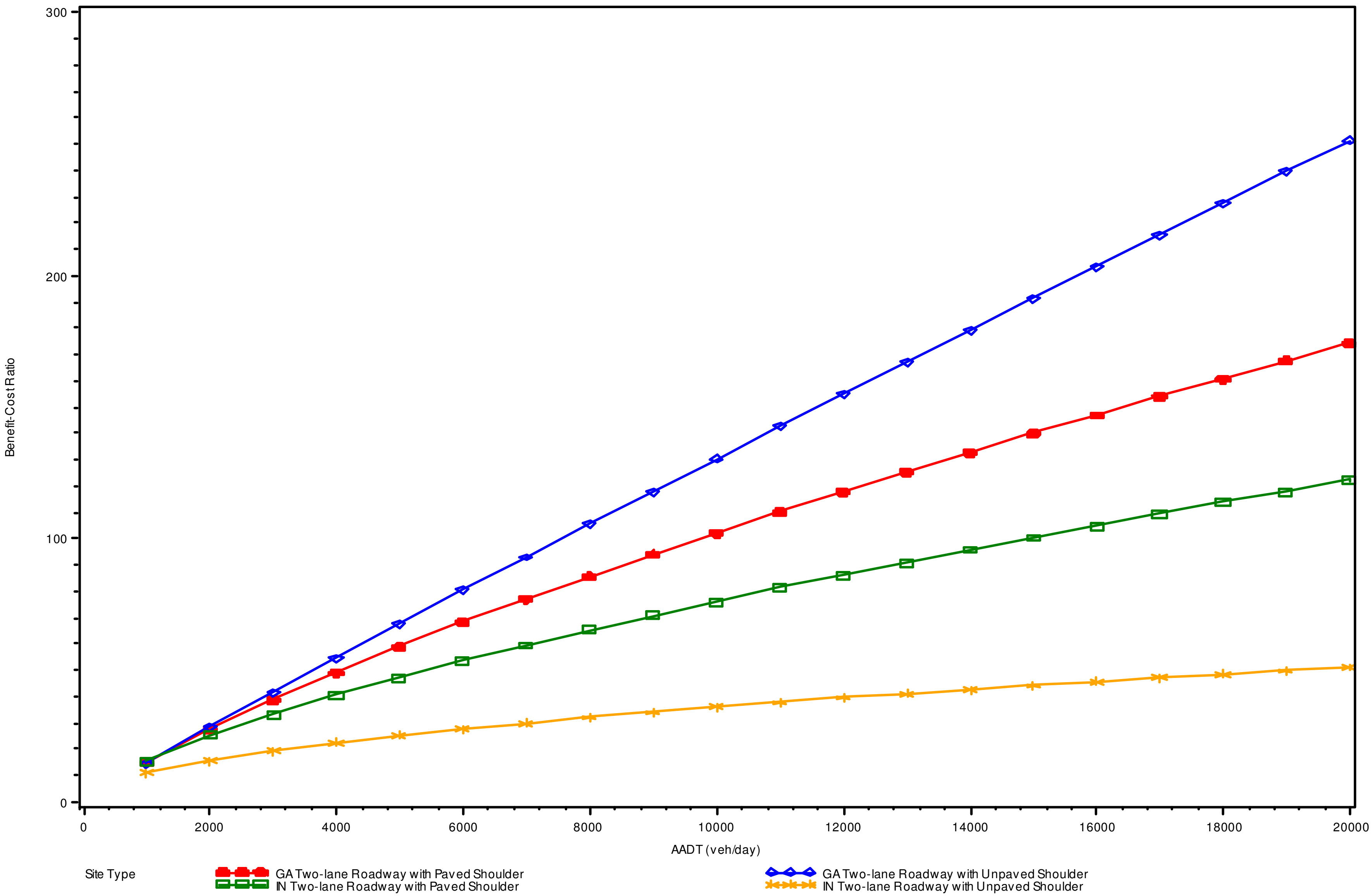

Figure 7. Maximum Benefit-cost Ratios for the Safety Edge Treatment as a Function of AADT

Section 7. Conclusions

Conclusions from the analysis of pavement-shoulder drop-off field measurements and crash data, based on three years of data for the period after resurfacing and after installation of the safety edge treatment, are presented below:

1. The EB evaluation results for the safety edge treatment with three years of crash data for the period after resurfacing found that 56 of the 81 comparisons show a positive safety effect for the safety edge treatment. However, only 11 of these comparisons were statistically significant, which may be due in part to the small magnitude of the safety edge effect.
2. The EB evaluation results indicate that for all two-lane highway sites in two states the best estimate of the effectiveness of the safety edge treatment is a reduction of approximately 5.7 percent in total crashes. While this result was not statistically significant the evaluation results obtained for total crashes were nearly always in the positive direction. The results of separate evaluations for fatal-and-injury crashes and property-damage-only crashes are too variable to draw conclusions.
3. Benefit-cost analysis based on the estimated 5.7 percent crash reduction effectiveness of the safety edge treatment found that this treatment is so inexpensive that it is highly cost-effective for application in a broad range of conditions on two-lane highways. Computed minimum values for benefit-cost ratios ranged from 4 to 44 for two-lane highways with paved shoulders and from 4 to 63 for two-lane highways with unpaved shoulders. The benefit-cost ratios generally increase with increasing traffic volume and are higher where the cost of installing the safety edge treatment is lower.
4. The cost of adding the safety edge treatment to a resurfacing project is minimal. Comparisons of overall project costs and overall cost of HMA resurfacing material did not show an increase for resurfacing projects with the safety edge when compared to normal resurfacing projects without the safety edge. However, computations based on the volume of asphalt required to form the safety edge suggest that the cost of the safety edge treatment is approximately $333 to 1,333 per km ($536 to 2,145 per mi) for application to both sides of the roadway combined.
5. Resurfacing with or without the safety edge treatment was found to decrease the proportion of drop-off-heights that exceed 51 mm (2 inches), at least in the short term. However, there is little evidence that resurfacing with the safety edge treatment creates more high drop-offs than resurfacing without the safety edge treatment. Data for drop-off heights showed that the proportion of drop-offs on both treatment and comparison sites increased in the second and third years after resurfacing. There is no present evidence that the safety edge treatment

sites have more high drop-offs than the comparison sites that did not have the safety edge treatment.

6. Evaluation results for the effect of the safety edge treatment on run-off-road crashes and drop-off-related crashes on two-lane highways were more variable and inconsistent. More sites and higher crash frequencies would be needed to obtain consistent, statistically significant results. Two trends were evident in the EB analysis of run-off-road and drop-off-related crashes. First, the safety edge treatment generally appears to have a positive effect on safety for all site types except for sites with unpaved shoulders in Indiana. This variability in results has not yet been fully explained. Second, however, the negative safety edge effects for Indiana sites with unpaved shoulders may be explained by low frequencies of drop-off-related crashes on comparison sites in the period before resurfacing.

7. There were not enough sites at which the safety edge treatment was applied on rural multilane highways to obtain meaningful evaluation results. However, the physical role of the safety edge treatment is no different on multilane highways than on two-lane highways. Results of the cross-sectional analysis, while not definitive, suggest that the safety edge treatment is effective on multilane highways.

8. An increase in total crashes for the first 12 to 30 months after resurfacing has been noted in previous studies of the effect of resurfacing on crashes *(5)*. The observed increase in crash frequency for the period immediately after resurfacing may result from this effect. The use of three years of crash data after resurfacing resulted in more realistic estimates of the safety effectiveness of the safety edge than analysis using just one or two years of data.

9. A test of the proportion of fatal-and-injury crashes after resurfacing indicates that the proportion of fatal-and-injury crashes decreased significantly after resurfacing. However, there is no apparent shift in crash severity distributions between sites that were resurfaced with and without the safety edge treatment.

10. In summary, resurfacing appears to increase crash frequencies, at least in the short term, and to reduce crash severities. Incorporating the safety edge treatment in a resurfacing project appears to reduce crash frequencies slightly but to have no effect on crash severities.

Section 8. Recommendations

1. The safety edge treatment is suitable for use by highway agencies under a broad range of conditions on two-lane highways. While the evaluation results for total crashes were not statistically significant, there is no indication that the effect of the safety edge treatment on total crashes is other than positive.
2. Although the overall effectiveness of the safety edge treatment found in this study was not statistically significant, this is not surprising given that the magnitude of that safety effect appears to be small (i.e., approximately 5.7 percent). However, the safety edge treatment is so inexpensive that its application under most conditions appears to be highly cost effective. The effect of the safety edge treatment would be cost effective for two-lane highways with traffic volumes over 1,000 veh/day even if its effectiveness were 2 percent, rather than 5.7 percent.
3. The cost-effectiveness of the safety edge treatment increases with increasing traffic volumes. For roads with higher traffic volumes, the safety edge treatment is highly cost effective.

Section 9. References

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Appendix A
Identification of Drop-Off-Related Crashes

All crashes obtained from the participating agencies were screened and crashes that were not relevant to the study were excluded. All remaining crashes were then classified into whether one or more of the involved vehicles ran off the road. Then, each run-off-road crash was classified as to whether it was potentially related to a pavement edge drop-off. Differences in accident reporting between agencies led to individualized classification criteria for each agency. The classification criteria and data elements used for each agency are described in Table A-1.

Table A-1. Classification Criteria for Crashes

Classification	Georgia	Indiana	New York
Excluded crashes	Intersection and intersection-related	Intersection and intersection-related	Intersection and intersection-related And Non-reportable crashes and non-injury crashes (with less than $1,000 in property damage to any vehicle) since these crashes were not available for all years
Run-off-road crashes	If Harmful Event included a roadside object or if Location of Impact was off the roadway	If any vehicle Collided With a roadside object or if Manner of Collision was ran-off-road or if Primary Factor was ran-off-road right or ran-off-road left	If Accident Type involved a roadside object or if Location of First Harmful Event was off the roadway or if Second Event for any vehicle involved a roadside object
Drop-off-related crashes	If Crash Road Type was defective shoulders or “Holes, Deep Ruts, Bumps” or if Driver Contributing Factor indicated driver lost control	If Primary Factor was overcorrecting/over-steering	If Contributing Factor for any involved vehicle was defective shoulder

Appendix B
Pavement Edge Drop-Off Data Collection Methodology

This appendix presents the methodology used to collect field measurements for pavement edge drop-offs.

Selection of Data Collection Locations

Several data collection locations were selected within each resurfacing project site to obtain field measurements of pavement edge drop-offs. Data collection locations were generally 3 to 6 km (2 to 4 mi) apart. There were typically three to four data collection locations within each site, depending on the overall site length.

Each data collection location was predefined as being a specified distance, in whole miles, from the start of the site. Then, to remove bias from the data collection process, a random offset was added to the predefined distance. This random offset, selected separately for each data location, was 0.16 to 1.45 km (0.1 to 0.9 mi), increments of 0.16 km (0.1 mi). The location defined by the predefined distance plus the random offset was used as the starting point for data collection. Field data collection personnel were given discretion to move the starting point, if appropriate, if the measurement location was clearly not representative of the roadway as a whole, or if sight distance was too limited for measurements to be made safely. Data were not collected at a selected location if recent maintenance had occurred or if the weather did not permit data to be collected safely or accurately.

Field Measurements

Roadway characteristics were recorded at the selected starting point and pavement edge drop-off height was measured ever 16 m (52 ft) on both sides of the roadway over a 0.16-km (0.1 mi) interval beginning at the starting point. A field data collection form is illustrated in Figure B-1. The data collection intervals are illustrated in Figure B-2. The set of measurements illustrated in the figure was repeated at intervals of 3 to 6 km (2 to 4 mi) along the roadway, as described above.

The roadway characteristics recorded at the starting point of each data collection include:

- Speed limit
- Pavement type
- Shoulder type
- Shoulder grade
- Shoulder width
- Lane cross-slope
- Lane width
- Pavement edge drop-off shape
- Grade

Pavement Edge Drop-off Data Collection

County & State: ________________________ **Date:** __________________

Site: _______________ **Milepost:** __________ **(Page ___ of ___)**

Weather Condition: sunny partly cloudy overcast

Main St. (include gov and local names): ____

Begin cross-street: ____

End cross-street: ____

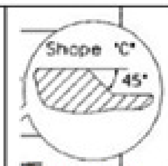
Speed Limit: ___________ **Orientation:** N / S E / W

Pavement Type: Asphalt Concrete

Shoulder Type:

asphalt	concrete	gravel	earth	mixed / varies
N / S / E / W	N / S / E / W	N / S / E / W	N / S / E / W	N / S / E / W

Circle pavement edge shape:

				
Sharp break-off or concrete	overlay, may be more jagged	Wedge in place	Safety Edge	Other (draw)
N / E S / W	N / E S / W	N / E S / W	N / E S / W	N / E S / W

random start point (mi)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

	Grade (%)	Width (ft)
N or E Shoulder		
S or W Shoulder		
N or E Lane		
S or W Lane		
Road Grade (if sig)		up / down

Horizontal Curve left right none

Vertical crest sag none

Initial Grade ______ up down

Final Grade ______ up down

Roadside Rating ______

Additional Comments:

Dist from Start Pt	N / E	S / W
0 (ft)		
52 (ft)		
104 (ft)		
156 (ft)		
208 (ft)		
260 (ft)		
312 (ft)		
364 (ft)		
416 (ft)		
468 (ft)		
520 (ft)		

Figure B-1. Sample Data Collection Form

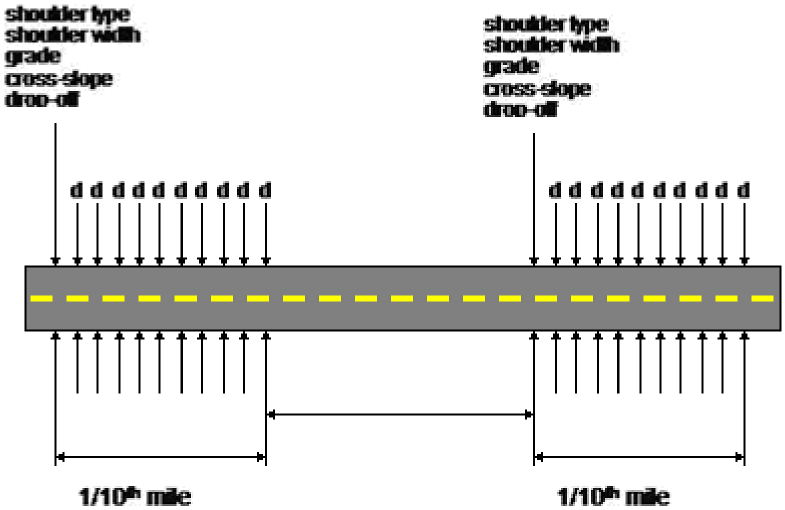


Figure B-2. Data Collection Intervals

Shoulder Type and Width

Shoulder types were generally recorded as paved, gravel, or earth. When a mixture of shoulder types was found (i.e., a composite shoulder), the width of paved shoulder beyond the edge of the traveled way was recorded and the presence of the other shoulder type was noted.

Drop-Off Shape

Drop-off shapes are shown in the data collection form in Figure B-1. Shapes A, B, and C were defined in other literature. Most shapes correspond to A, B, or C. Shape A typically corresponds to concrete pavement edge shape. The likely cause of such drop-offs is settling of the concrete pavement. It may also occur when asphalt pavement breaks. Shape B is the most common shape for drop-offs at the edge of an asphalt pavement. It is the shape that occurs from a typical overlay. Shape C corresponds to the safety wedge. It is recorded when the edge shape is angled at approximately 45 degrees and appears to be intentionally shaped at that angle. Other drop-off shapes were recorded, when present.

Lane Width and Pavement Width

Both pavement widths (i.e., traveled way width) and lane widths were measured. Lane widths were measured from the edge of the lane to the painted centerline of the roadway. Where no centerline was present, the lane width was calculated as half of the total pavement width. Where pavement extended 100 mm (4 in) or less beyond the pavement edge line, it was included in the lane width. Where pavement extended 100 mm (4 in) or more beyond the pavement edge line, it was treated as a paved shoulder.

Drop-Off Height

Drop-off height was measured to the nearest 3.18 mm (0.125 in) since most measuring tools measure in 3.18 mm (0.125 in) increments. Additionally, measurement tools marked with 3.18 mm (0.125 in) increments have been found to be easier to read consistently than those marked with 2.54 mm (0.1 in) increments. It is assumed that a tire could still catch on just a few inches of drop-off, even if shoulder material is at grade beyond that distance. Therefore, drop-off height is measured approximately 100 mm (4 in) from the edge of pavement for Shape A, or 100 mm (4 in) from the base of the pavement for Shapes B and C (see Figure B-3).

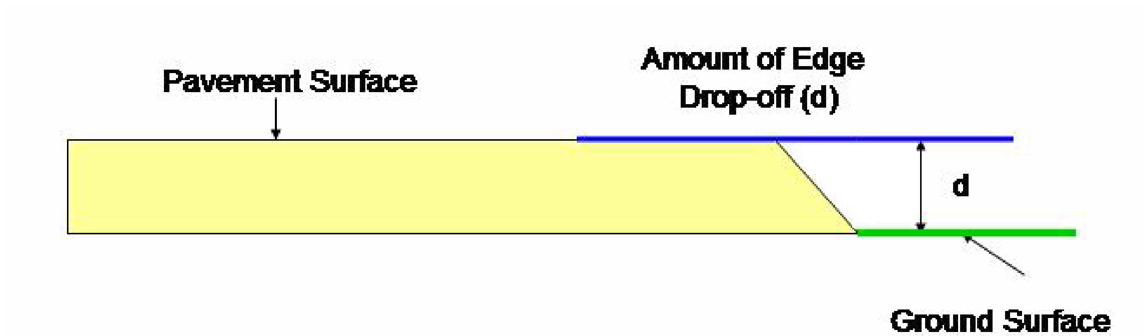


Figure B-3. Measurement of Pavement Edge Drop-Off Perpendicular to Pavement Surface

Drop-off height is measured by placing a level across the top of the pavement surface so that it overhangs the shoulder. A ruler is then used to measure the vertical distance between the shoulder and the level at the appropriate location as discussed above. Drop-off height is measured from the ground to the base of the level as shown in Figure B-4.

Pavement edge drop-off height is not measured at driveways or minor intersections if they coincide with a planned data collection point. If a driveway or intersection is located at a data collection point along a segment, data collectors record that information and move to the next data collection point.

Figure B-4. Measurement of Pavement Edge Drop-Off Height

Appendix C
Scatter Plots of Accidents and AADT

The following are scatter plots of crashes (per mile per year) and traffic volume (log basis), which were used to determine the appropriateness of modeling assumptions. In general, these plots show a positive relationship between crashes and traffic volume (i.e., crashes increase with increasing volume). Also, distributions for comparison, treatment, and reference sites appropriately overlap each other and do not contain extreme outliers.

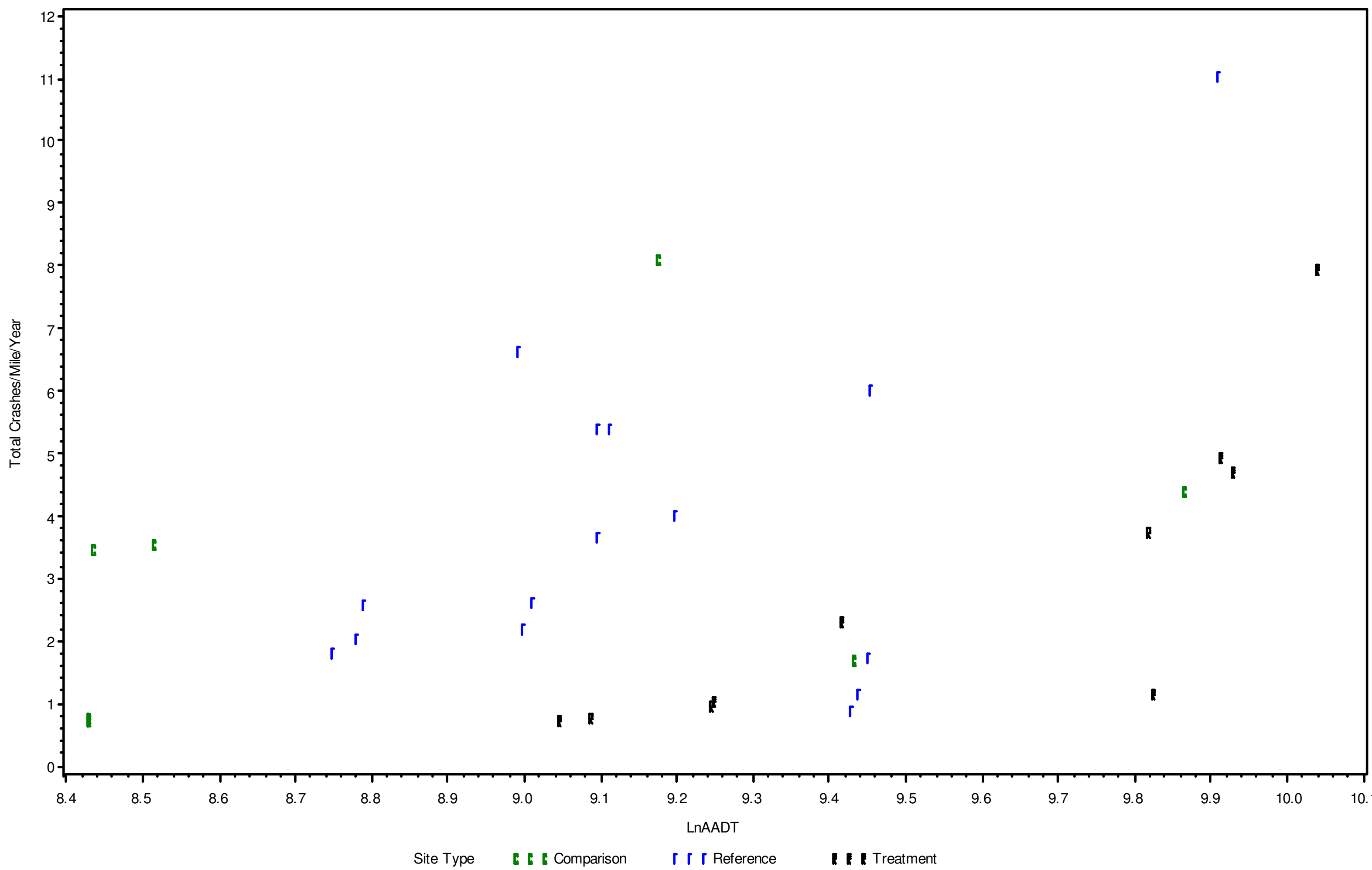


Figure C-1. Georgia Multilane Roadway with Paved Shoulder

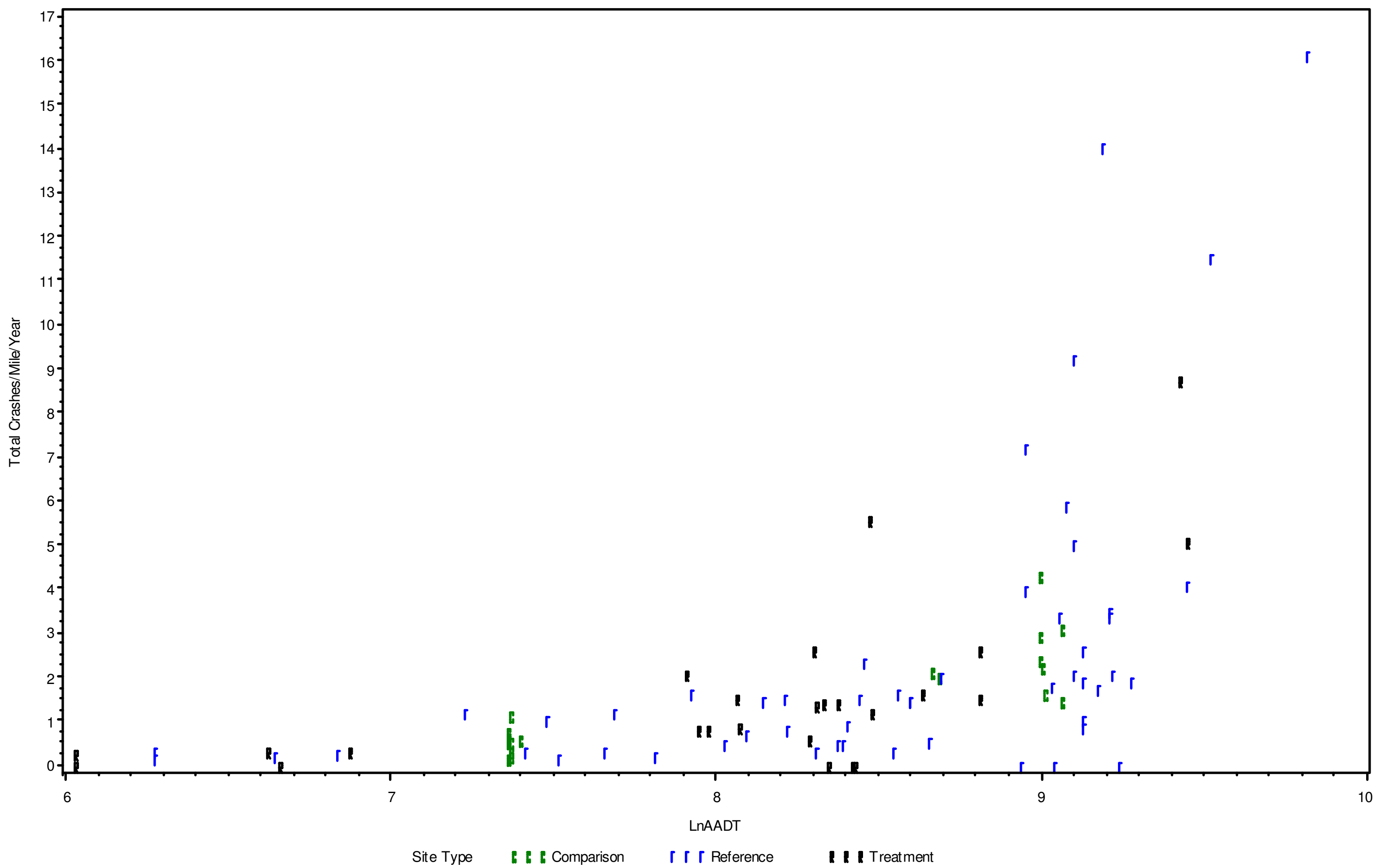


Figure C-2. Georgia Two-lane Roadway with Paved Shoulder

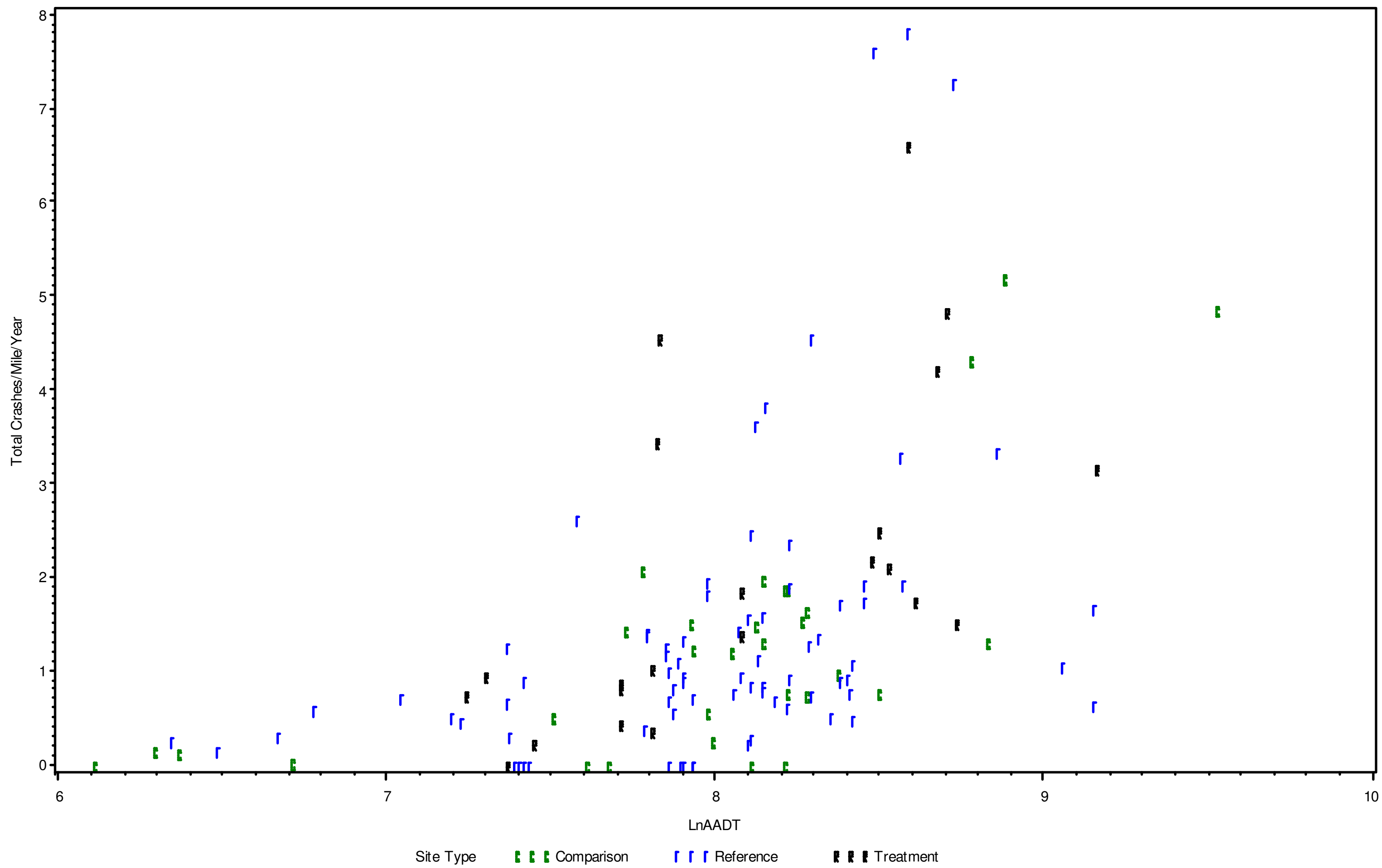


Figure C-3. Georgia Two-lane Roadway with Unpaved Shoulder

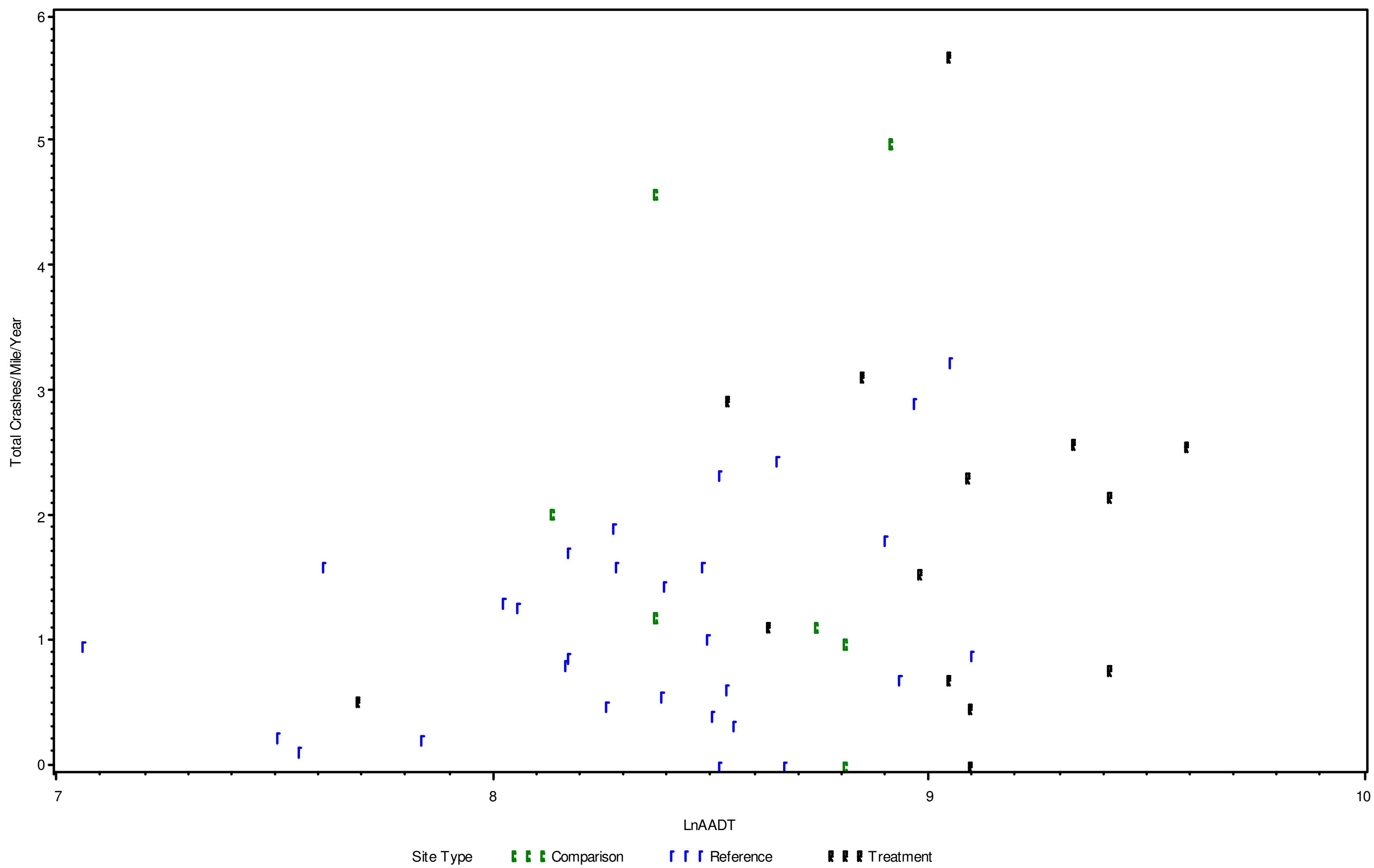


Figure C-4. Indiana Two-lane Roadway with Paved Shoulder

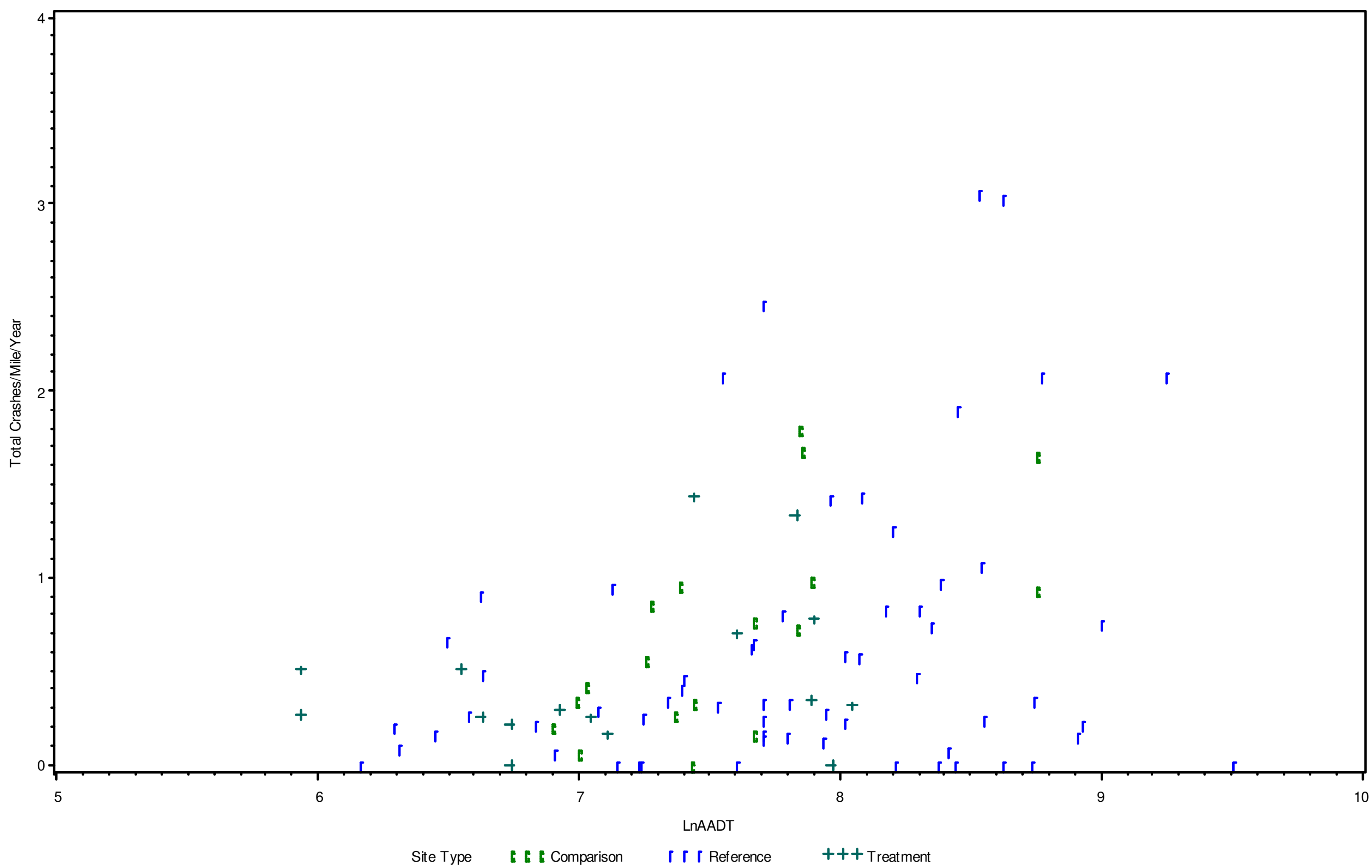


Figure C-5. Indiana Two-lane Roadway with Unpaved Shoulder